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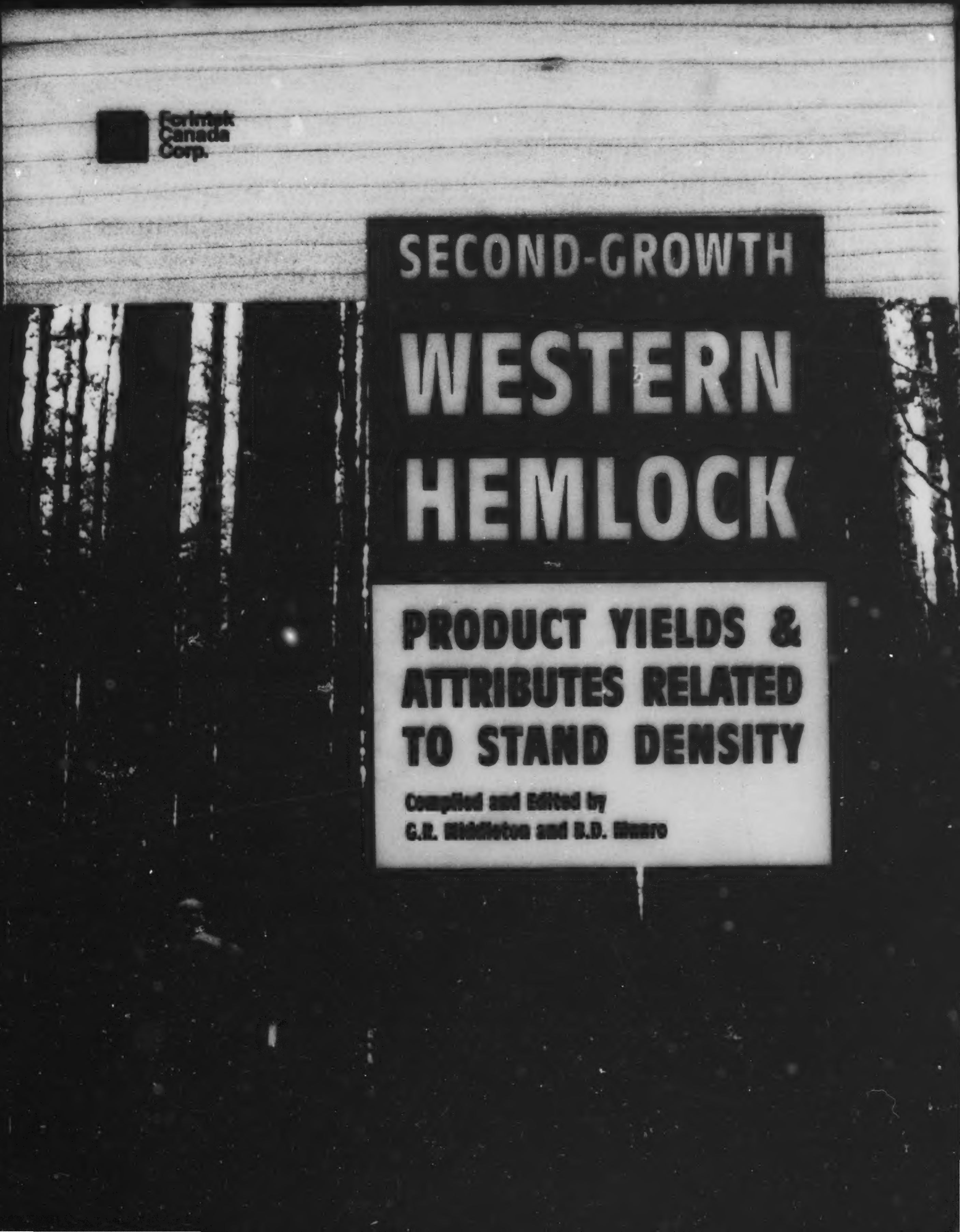

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SECOND-GROWTH
WESTERN HEMLOCK

PRODUCT YIELDS & ATTRIBUTES RELATED TO STAND DENSITY

Compiled and Edited by
G.R. Middleton and B.D. Munro

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ABSTRACT

The effect of stand density on 90-year-old western hemlock tree and wood characteristics was determined to assist foresters with stand density management. Trees were selected from three Vancouver Island stands. Stand densities were 580 and 930 stems per hectare (sph) at two northern locations, and 930 sph at a stand 500 km south. Mean breast-height wood densities were .42, .45 and .47 respectively. The 580 sph stand trees had the fastest early growth rate, were taller, larger in diameter, had the largest branches, and highest taper. The southern 930 sph stand had the slowest early rate-of growth. Tested in bending, lumber mean modulus-of-elasticity (MOE) and mean modulus-of-rupture (MOR) differed significantly by stand density, and average early growth rate. The 580 sph stand had the lowest proportions of high grade structural lumber and the lowest MOE and MOR values. Structural properties of veneer, LVL, and small clears were consistent by stand with those of lumber. Lumber machined as well, and treated more easily than old-growth hemlock. Kraft and TMP pulp properties did not differ significantly by stand. Kraft pulp yields were 1 to 2 percent higher than those published for western hemlock.

Keywords:

Second-growth, western hemlock, Tsuga heterophylla, stand density, growth rate, juvenile wood, lumber, veneer, LVL, machining, treated wood, mechanical properties, pulp properties, Kraft pulping, Thermomechanical pulping.

SUMMARY

Introduction

In British Columbia second-growth western hemlock (*Tsuga heterophylla* (Raf.) Sarg) remains a small proportion of harvested volume, but represents an increasing area of young stands that are subject to silvicultural treatment. Foresters need information quantifying the effect of stand density management on tree characteristics and important wood attributes.

Methods

Two hundred 90-year-old western hemlock trees were selected from three natural stands on western Vancouver Island. Two stands (PH580 and PH930) located near Port Hardy at latitude 50° 36′; longitude 127° 30′ had stand densities of 580 and 930 stems per hectare (sph) and site index at 50 years of 39 and 32 respectively. The third (PR930) located at Port Renfrew, at latitude 48° 35′; longitude 124° 21′ had stand density of 930 sph and site index 30.

Tree samples were selected systematically by diameter-at-breast height (d.b.h.). Tree dimensions, quality and pathological indicators were recorded. Sample trees were felled, stems were scaled and graded, and knots and knot indicators were measured and recorded. Stems were cut to 4 m lengths and the first 15 and 30 annual rings from the pith were marked on log ends to represent two measures of juvenile wood.

Logs equal to or greater than 25 cm small-end diameter were sawn to Japanese lumber sizes, primarily 105x105 mm squares. The lumber was kiln dried, planed and graded to both Japanese (JAS) and North American (NLGA) rules for structural lumber. Lumber was also graded to both rules based on consideration of knots only.

All structural grade lumber was tested in bending to determine modulus-of-rupture (MOR) and modulus-of-elasticity (MOE). Depending on dimension, bending tests were done in accordance with ASTM D4761 or ASTM D198. Data were related to individual trees for analysis of stand and tree growth effects.

Sub-samples of lumber were selected from the PH580 and PH930 stands by juvenile wood content and tested for treatability with a water-borne preservative, chromated copper arsenate (CCA) and a solvent-borne preservative, acypetacs copper (Cuprinol). Additional lumber samples were selected by stand and juvenile wood proportion and tested for machining (planing, sanding, shaping, boring and mortising) properties.

Three additional trees (small, medium and large) from each stand were obtained to test properties and yields of kraft and TMP pulps, veneer yields and Laminated Veneer Lumber (LVL) potential, and mechanical properties of small clears.

Results and Discussion

For PH580, PH930 and PR930 respectively, mean breast-height diameters were 42.7, 32.8 and 32.5 cm. Mean heights were 43.8, 37.3, and 34.9 m. Mean percent basal areas of first 30 years growth were 46.4, 44.9 and 25.7%. Mean breast-height wood densities were .42, .45 and .47 respectively, compared to the species average of .45. Measured on logs, mean knot diameters were 1.50, 1.16 and 1.20 cm. The PH580 trees had the fastest early growth rate, were taller, larger in diameter, had the largest branches, and the highest taper. PH930 was distinguished from PR930 by faster early rate-of-growth. Figure 1 shows average ring widths by cambial age compared by stand.

Figure 1

Comparison of Average Annual Ring Width by Cambial Age

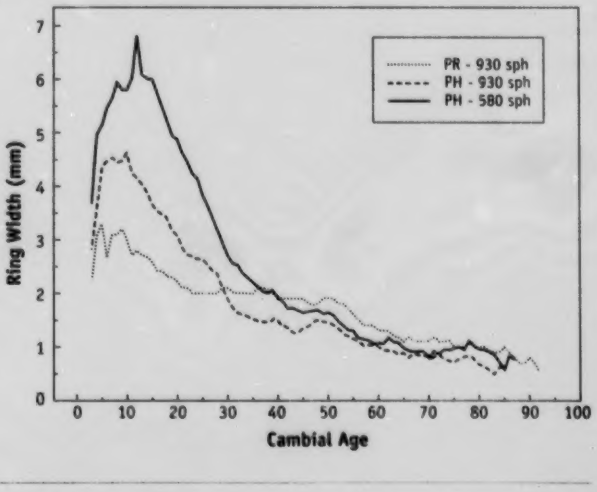
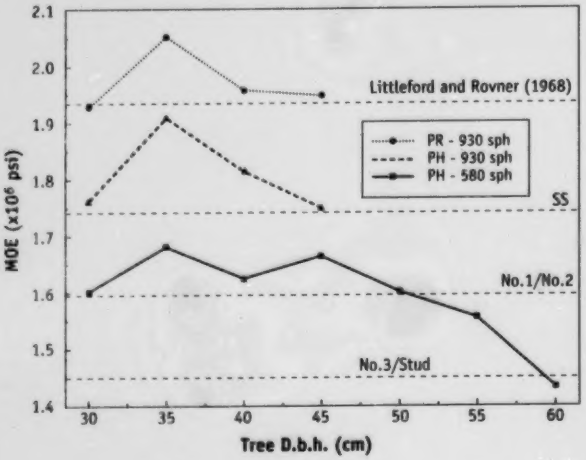


Figure 2
MOE for Select Structural 105x105 mm Squares Compared to Hem-Fir Code Values and to MOE for Select Structural Old-Growth Western Hemlock



Log and Lumber Grades

Relatively higher proportions of PH580 log volume were assigned to high value log grades on the basis of larger log diameter. Lumber recovery was higher from PH580 larger diameter logs, but the proportion of premium NLGA and JAS grades obtained declined significantly as tree d.b.h. increased. Lumber from the PH580 stand yielded the lowest proportions of JAS No. 1 and NLGA Select Structural grades.

Lumber Structural Properties

Lumber from the PH580 stand had significantly lower mean MOE and MOR values compared to lumber from the two more dense stands, and fell below code values. Mean MOE and MOR values for lumber from the two 930 sph stands were also significantly different.

Figure 2 shows that mean MOE values for Select Structural 105x105 mm lumber obtained from the two 930 sph stands essentially met or exceeded existing code values for Hem-Fir. It also shows that mean MOE values for the slow grown PR930 stand exceeded a value published for old growth hemlock (Littleford and Rovner, 1968)

Mechanical Properties of Small Clears

Strength and stiffness values for small clears were consistent with those for tests of full sized lumber, but differences between material from the two 930 sph stands were not significant

Juvenile Wood And Branches

Juvenile wood zones 15 and 30 annual rings from the pith provided poor predictions of lumber strength and stiffness, but there were significant differences in mean MOE and MOR values between discrete 20 percent classes of juvenile wood. Increased proportions of juvenile wood were associated with significant reductions in MOE and MOR.

Various measures of knot size (measured on the logs) provided relatively poor estimates of percentage yields of premium NLGA and JAS lumber grades. Average knot size was generally the best measure of knot effects on lumber grade but easier to obtain knot indices proved to be nearly as effective. Predictions of mean MOE and MOR based on tree d.b.h. and breast-height wood density were improved only slightly by the inclusion of knot size.

Treatability

In terms of retention, fast-grown western hemlock from PH580 was more treatable than hemlock from PH930. Juvenile wood, defined as the first 15 annual rings, was less treatable than 16-to-30 ring juvenile wood with both CCA and Acypetacs Copper. Full cell treatment of 16-to-30 ring juvenile wood with CCA achieved the requirement for decking lumber in CSA 080.32. There was no significant difference in treatability with Acypetacs Copper between PH580 and PH930. Double vacuum treatment of second-growth hemlock with Acypetacs Copper achieved the target penetration for protection of joinery grade lumber. Second-growth western hemlock was much more treatable with CCA than old growth.

Machining Properties

Machining tests showed no significant differences by stand. Second-growth western hemlock machined as well as old-growth.

Veneer and LVL

Structural properties of veneer and LVL were consistent by stand with those of lumber. Logs from PH930 and PR930 produced high yields of structural veneer suitable for LVL. For all bolts tested, 82.5 percent of the veneer obtained was suitable for making structural LVL. The larger, lower density logs from PH580 had higher recovery suitable for the production of plywood.

Pulp Properties and Yields

There were no significant differences in pulp properties between the stands, but in thermomechanical pulping, mature wood obtained from PH580 exhibited poorer tensile strength compared to that from the other two stands. Second-growth western hemlock kraft pulp yields at kappa 30 exceeded published values by 1 to 3 percent.

Conclusions

Consistent results were obtained for solid wood properties. Trees from the lower stand density and higher site index stand, PH580, were characterized by comparatively rapid early growth rate, lower average wood density and larger branch size. These characteristics in turn resulted in lower structural properties observed for lumber, veneer and small clear wood specimens. Early rate-of-growth proved to be a more effective measure than stand density at 90 years for discriminating stands on the basis of wood attributes. Early growth rate at PH930 exceeded that at PR930, and was associated with significantly lower breast-height average wood density and, for the most prevalent lumber dimension, significantly lower lumber strength and stiffness properties.

Second-growth western hemlock in general treated more readily than old-growth western hemlock and could find value in markets for treated wood products. It machines as well as old growth. Kraft pulp yields from second-growth western hemlock exceeded published values which should significantly improve digester productivity.

Foresters responsible for stand density management can expect that second-growth western hemlock from stands similar to PH930 and PR930 will have structural properties that meet or exceed code standards for Hem-Fir. Lower structural properties of products obtained from PH580 suggest that, on high sites, stand managers wanting to produce trees with structural attributes comparable to old-growth western hemlock should consider relatively high initial stand densities. However, the high site index (39) recorded at PH580 represents less than one percent of the coastal western hemlock region of British Columbia.

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Gerry Middleton and Dave Munro
Project Leaders

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SECTION

1 INTRODUCTION

G.R. Middleton and B.D. Munro

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SECTION 1

INTRODUCTION

1 Background

The future of the forest industry in Canada will increasingly depend on the conversion of managed second-growth timber. In some regions of the country, and for some species, a shift to harvesting naturally regenerated second-growth forests has already occurred. Information on the product attributes of second-growth is needed to help industry develop optimum conversion and marketing strategies. Information quantifying the effects of growing conditions on wood attributes is needed by forest managers for consideration in silvicultural decisions. "The forest manager needs to consider the impact of silviculture treatment on the volume, quality, and value at harvest if they (sic) wish to maximize their return on investment" (British Columbia Ministry of Forests, 1999).

Forintek Canada Corp., in cooperation with the Pulp and Paper Research Institute of Canada and the British Columbia Ministry of Forests has undertaken a program of research into the tree characteristics and wood attributes of second-growth timber in British Columbia. Kellogg, *et al.* (1989), completed a comprehensive assessment of second-growth coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco). Middleton, *et al.* (1995) and Middleton, *et al.* (1996) determined the effect of stand density on product attributes of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.). Jozsa, *et al.* (1998), as a prelude to this study, examined the basic wood properties of second-growth western hemlock (*Tsuga heterophylla (Raf.)* Sarg.) and Sauter, *et al.* (1999) determined the influence of thinning on the wood density and branch size of western larch (*Larix occidentalis* Nutt.).

The present study was undertaken to provide comprehensive information about the wood properties and product attributes of coastal second-growth western hemlock, and to determine the extent to which these properties and attributes are affected by differences in stand density. Part one of the study examined the characteristics and log quality of 200 trees, and determined lumber structural, appearance, treatability and machining properties. Part two evaluated veneer and pulp properties and the mechanical properties of small clear wood specimens for nine additional trees.

Stand Management and Wood Quality

Concern about the quality of wood from second-growth trees is not new. Warrack, (1948) suggested that serious consideration should be given to thinning and pruning natural stands of Douglas-fir because without silvicultural treatment second growth would not produce high quality lumber within 100 years. Paul, (1957) observed that the stand management objective of rapid tree growth conflicted with wood quality objectives of small branches and low proportions of juvenile wood. He suggested that too little attention was given to remedial and management practices that could compensate for these limitations. Benson, (1960) echoed this concern and suggested that restricting core wood development would be necessary if trees were to be produced that were suitable for other and more valuable uses than fibre products. He felt this was all a matter of forest management.

Senft *et al*, (1985) observed that plantation trees harvested at an early age contain high proportions of juvenile wood, which tends to shrink, warp and break under stress. They admonished foresters to grow trees with smaller cores of juvenile wood or to find species or varieties with acceptable juvenile wood properties.

Kellogg *et al*, (1989) reported the results of a comprehensive study to determine the basic properties and product attributes of wood from second-growth Douglas-fir. They concluded that, largely due to high proportions of juvenile wood, these trees have physical, mechanical and chemical properties substantially different from the old growth resource. Lumber drying defects increased, and strength and stiffness decreased as proportions of juvenile wood increased.

Middleton *et al*, (1995) reported results of a lodgepole pine product conversion study. Based on conversion and test results from 220 trees, they determined that lumber from trees selected from a stand density of 700 stems per hectare (sph) at 90 years of age was substantially lower in strength and stiffness than lumber from trees selected from higher stand densities (1100 and 1900 sph) of the same age. Lower strength and stiffness was attributed to lower basic wood density and larger branch size in faster grown trees found in the more open stand.

Stand density management remains a contentious issue and stand density decisions are made difficult because foresters still lack basic information linking tree growth to product value (Middleton et al. 1995). A Stand Density Management Working Group in British Columbia noted that "technically sound, stand density management demands a structured process of thought and analysis based on knowledge from a number of disciplines" (British Columbia Ministry of Forests, 1999). Until now, there have been no comprehensive studies of the effects of stand density on end-product attributes of second-growth western hemlock (Gonzalez, 1996).

Western Hemlock in British Columbia

In terms of volume, western hemlock is the dominant coastal species in British Columbia, and one of the most important commercial tree species in the province. In the coastal forest region the mature standing volume of western hemlock is 1,235 million m³. When this is combined with an additional mature volume of 584 million m³ of hemlock in the interior, it represents 22 percent of the total mature softwood volume in the province (COFI, 1993). In 1996/97 western hemlock represented 33 percent of the total volume cut in the coastal region, based on volumes for which stumpage was billed (British Columbia Ministry of Forests, 1997).

In British Columbia western hemlock remains essentially an old-growth species. Inventory statistics available for the coastal Timber Supply Area[1] (TSA), show that western hemlock is the leading species on 1,825,407 hectares (ha). This represents 50 percent of the total TSA of 3,648,532 ha. Total timber volume[2], where western hemlock predominates is 786,672,000 m³, and of this volume approximately 71 percent is 250+ years old, and 87 percent is 141+ years old. Trees less than 121 years of age, classed as immature, represent only 11 percent of the total volume, and trees in the 81-100 age class sampled in this study represent only 2.3 percent. Considered on an area basis, however, some 26 percent of the western hemlock growing area in the coastal TSA is immature forest, and 14 percent (253,975 ha) is comprised of trees less than 41 years old.

The above statistics demonstrate that second-growth western hemlock sufficiently mature for harvesting represents only a small percentage of the total western hemlock resource, and that this will be true for several decades. In the future, as second-growth western hemlock enters the market its attributes will be questioned and compared, not only to those of old-growth western hemlock, but also to those of competing species. There is time to demonstrate the technical attributes of this resource and to develop effective conversion and marketing strategies. On the other hand, investment in silviculture has increased substantially in British Columbia and foresters are making stand management decisions today which will influence the future properties of western hemlock. If we include late commercial thinning, a quarter million ha of western hemlock forested land (aged 1 to 40 years) in the coastal TSA can be considered potentially available for some form of silvicultural intervention. This gives greater urgency to our objective to quantify the effects of growing conditions on wood attributes.

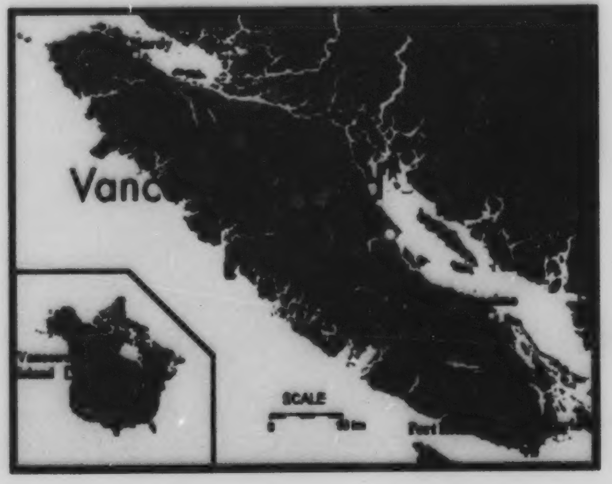
Stand and Tree Selection

Surveys were made of naturally regenerated[3] second-growth western hemlock stands in the lower mainland and Vancouver Island regions of British Columbia. Based on preliminary assessments of stand density and age, five stands were selected for comparison of basic wood properties (Jozsa, *et al.*, 1998). Three of these stands were subsequently sampled for this study. Two were selected to provide a comparison of a relatively open stand (580 sph) and a denser stand (930 sph) in close proximity to each other. The third (930 sph) was selected to provide a comparison of two relatively dense stands geographically removed. The stands are illustrated in Plate I.

The three stands sampled were located on the west coast of Vancouver Island. The two in close proximity to each other were at the eastern end of Rupert's Inlet west of Port Hardy. These were designated PH580 and PH930 to reflect their location and stem count. The third was located at Port Renfrew, near the southern end of the Pacific Rim National Park, and was designated PR930. Rupert's Inlet is at latitude 50° 36', longitude 127° 30'. Port Renfrew is located at latitude 48° 35', longitude 124° 21'. Stand locations are indicated in Figure 1-1.

PH580 was on a riparian zone a few metres above sea level. PH930 was on a gentle west-facing slope a little inland and approximately 100m above the inlet. The Port Renfrew stand, PR930, was less than 50 m above sea level, and was exposed to the open coast at the northern entrance to the Strait of Juan de Fuca. High fern dominated the undergrowth at PH580,

Figure 1-1
Sampling Locations



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[1] In 1995/96 approximately 64 percent of the area harvested in the coastal region was in the coastal TSA. It excludes Tree Farm Licences and privately owned timber.

[2] 17.5 cm minimum d.b.h., close utilization less decay, waste and breakage to a 10 cm top

[3] In British Columbia, plantations 80-100 years of age are not available, and it is necessary to sample naturally regenerated stands which have fortuitously replicated stand densities of interest. Differences in initial stocking can be inferred from growth and yield data for coastal western hemlock on similar sites given the comparative data on early growth rates recorded in this study.

PLATE I : *Sample Stands*

PH580

PH930

PR930

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Table 1-1 Tree Sample

Tree D.b.h. (cm)	Site PH580	(Number of trees) PH930	 PR930	Total
17.5 - 22.4		10	10	20
22.5 - 27.4	10	10	10	30
27.5 - 32.4	10	10	10	30
32.5 - 37.4	10	10	10	30
37.5 - 42.4	10	10	10	30
42.5 - 47.4	10	10	10	30
47.5 - 52.4	10			10
52.5 - 57.4	10			10
57.5 - 62.4	10			10
Total	80	60	60	200

while undergrowth at PH930 was predominately flat moss. A sparser undergrowth at the PR930 stand was predominantly fern with minor presence of salal. The three stands were within the wet or very wet hypermaritime subzone of the Coastal Western Hemlock Biogeoclimatic Zone (CWH). The CWH is the most productive forest zone in Canada (British Columbia Ministry of Forests, 1991).

Sampling for the conversion study was stratified to obtain the range of tree size represented in each stand. On the PH580 site 10 trees were selected in each of eight 5 cm diameter-at-breast height (d.b.h.) classes with cell midpoints that ranged from 25 to 60 cm. On the PH930 and PR930 sites, tree size was more limited in range, and 10 trees were selected in each of six 5 cm classes with mid-points that ranged from 20 to 45 cm. A total of 200 trees were selected. The tree sample is shown in Table 1-1 .

Three additional trees (one small, medium and large diameter) were selected and felled at each of the sampling locations to provide material needed for preliminary determinations of pulp and veneer attributes, and to test the mechanical properties of small clear wood specimens.

Log Storage

Study circumstances resulted in sample logs being stored for a year longer than expected. This unusual duration of log storage resulted in considerable surface checking and fungal attack on some log ends. These effects were evident in the lumber produced and resulted in some lumber being excluded from subsequent testing.

The additional trees selected to test pulp, veneer and small clear properties were trucked directly to Forintek's Vancouver laboratory following scaling and grading, and were not subject to prolonged storage. They were measured, marked and bucked to provide test material as illustrated in Figure 1-2.

Figure 1-2
Allocation of Tree Stems to Tests of Small Clears, Pulp and Veneer Properties

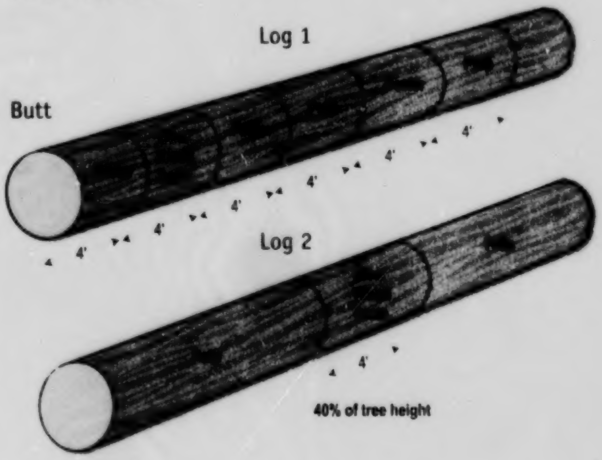

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Table 1-1 *Tree Sample*

Tree D.b.h. (cm)	Site PH580	Site PH930	Site PR930	Total
	(Number of trees)			
17.5 - 22.4		10	10	20
22.5 - 27.4	10	10	10	30
27.5 - 32.4	10	10	10	30
32.5 - 37.4	10	10	10	30
37.5 - 42.4	10	10	10	30
42.5 - 47.4	10	10	10	30
47.5 - 52.4	10			10
52.5 - 57.4	10			10
57.5 - 62.4	10			10
Total	80	60	60	200

while undergrowth at PH930 was predominately flat moss. A sparser undergrowth at the PR930 stand was predominantly fern with minor presence of salal. The three stands were within the wet or very wet hypermaritime subzone of the Coastal Western Hemlock Biogeoclimatic Zone (CWH). The CWH is the most productive forest zone in Canada (British Columbia Ministry of Forests, 1991).

Sampling for the conversion study was stratified to obtain the range of tree size represented in each stand. On the PH580 site 10 trees were selected in each of eight 5 cm diameter-at-breast height (d.b.h.) classes with cell midpoints that ranged from 25 to 60 cm. On the PH930 and PR930 sites, tree size was more limited in range, and 10 trees were selected in each of six 5 cm classes with mid-points that ranged from 20 to 45 cm. A total of 200 trees were selected. The tree sample is shown in Table 1-1 .

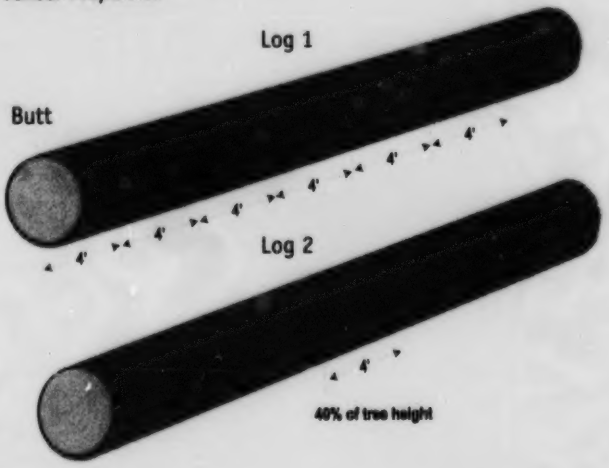
Three additional trees (one small, medium and large diameter) were selected and felled at each of the sampling locations to provide material needed for preliminary determinations of pulp and veneer attributes, and to test the mechanical properties of small clear wood specimens.

Log Storage

Study circumstances resulted in sample logs being stored for a year longer than expected. This unusual duration of log storage resulted in considerable surface checking and fungal attack on some log ends. These effects were evident in the lumber produced and resulted in some lumber being excluded from subsequent testing.

The additional trees selected to test pulp, veneer and small clear properties were trucked directly to Forintek's Vancouver laboratory following scaling and grading, and were not subject to prolonged storage. They were measured, marked and bucked to provide test material as illustrated in Figure 1-2.

Figure 1-2
Allocation of Tree Stems to Tests of Small Clears, Pulp and Veneer Properties



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SECTION

2

TREE CHARACTERISTICS, LOG AND LUMBER YIELDS

G.R. Middleton and B.D. Munro

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SECTION

2

TREE CHARACTERISTICS, LOG AND LUMBER YIELDS

1 Introduction

Site productivity and stand density are important determinants of timber yield and wood quality. Stand density affects tree growth rate and live crown retention, and these in turn influence stem form, branch size and average wood density. Site productivity determines how tree growth responds to differences in stand density.

Second-growth western hemlock trees were selected from the three stands on Vancouver Island previously described. Tree and log characteristics were measured to quantify the effect of stand density on these characteristics, and logs were converted to lumber to further quantify the effect of stand density in terms of wood product attributes.

2 Objective

To determine how differences in stand density influence tree and log characteristics of second-growth western hemlock, and how these characteristics affect wood attributes that determine end-product value.

3 Methods

Tree Measurements

Tree sampling was stratified by breast-height diameter class. Trees with severe crooks or forks in the lower two thirds were excluded, but trees were otherwise selected at random. The sample trees were labelled individually, and by stand of origin.

A quality cruise was made of each tree. This included measuring the following tree quality characteristics:

- diameter-at-breast height
- tree height
- crown dominance[1]
- heights to live crown and dead branch stubs
- number of knot free quarters in the 1st and 2nd 5m log
- incidence and severity of lean or sweep
- incidence and degree of spiral grain,

and incidence and severity of the following pathological indicators if present:

- scars
- frost crack
- fork
- crook
- dead or broken top
- mistletoe
- large rotten branches
- conk

A 5 mm increment core (bark-to-bark through the pith) was obtained at breast height for each sample tree to determine breast-height wood density[2] and growth rate, and to provide accurate annual ring counts for determining tree age.

Stand density was measured for the areas sampled by establishing fixed radius plots of 5.64 m (0.01 ha) around each sample tree.

Logging and Log Measurements

Sample trees were felled manually and bucked to close utilization standards (10 cm log top diameter) and to predetermined long-log lengths. During tree felling, measurements were made of stump heights, log lengths, lengths and location of any breakage, and the length and diameter of the last usable end piece. Logs were labelled with tree number and log position.

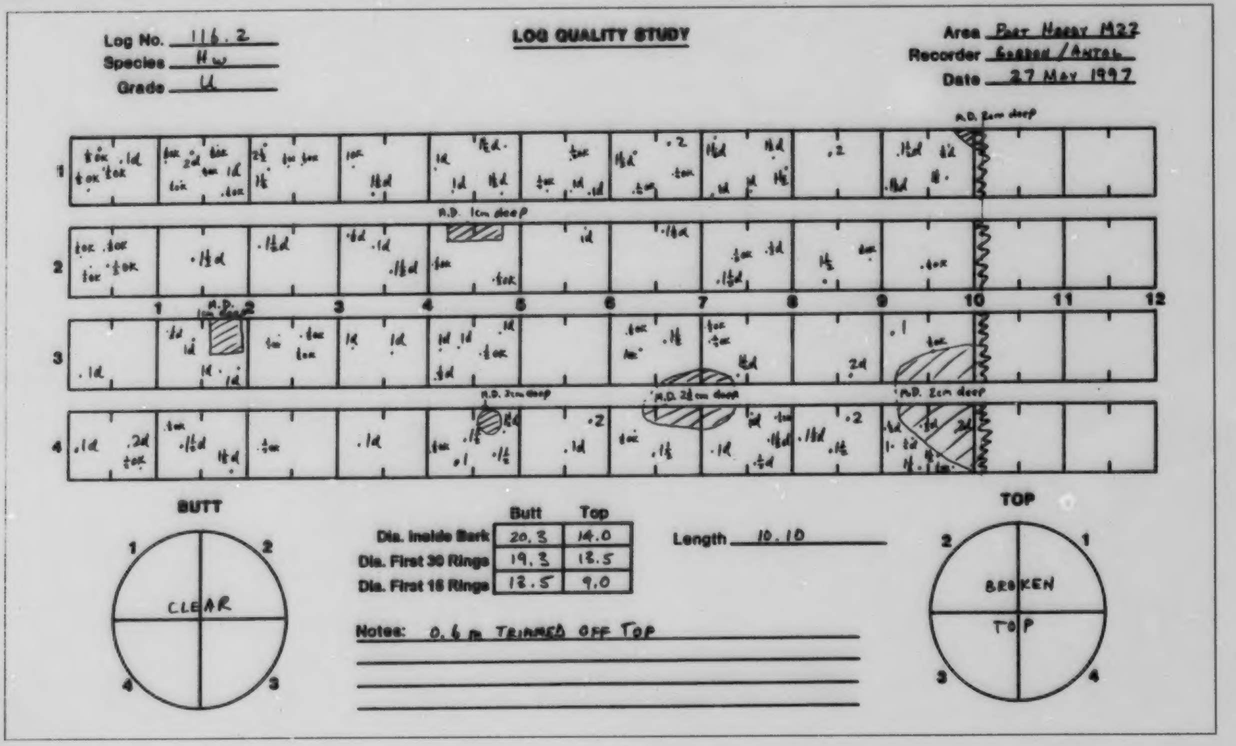
---

[1] Crown dominance refers to tree position in the crown canopy and was recorded as follows:

- Dominant – Trees with crowns extending above the general level of the crown canopy. Crowns are somewhat larger than average.
- Codominant – Trees with crowns forming the general level of the crown canopy. Crowns are generally smaller than those of dominant trees.
- Intermediate – Trees with crowns below, but still extending into the general level of the canopy.
- Overtopped – Trees with crowns entirely below the general level of the canopy.

[2] Here, and unless otherwise noted, throughout this report wood density refers to basic relative density calculated on an oven-dry weight, green volume basis.

Figure 2-1 Log Diagram



LOG QUALITY STUDY

Log No. 116.2
Species Hw
Grade U

Area PORT HARDY M27
Recorder [illegible] / ANTAL
Date 27 MAY 1997

	Butt	Top
Dia. Inside Bark	20.3	14.0
Dia. First 30 Rings	19.3	13.5
Dia. First 15 Rings	13.5	9.0

Length 10.10

Notes: 0.6 m TRIMMED OFF TOP

Logs were scaled by qualified industrial scalers according to the B.C. Firmwood Scale (British Columbia Ministry of Forests, 1999), which specifies the following measurements:

- Log top and butt end radii inside bark to the nearest cm
- Log length to the nearest 0.1 m
- Deduction of decay and voids

Log volumes were calculated using Smalian's[3] formula.

Logs were graded according to BC Ministry of Forests' statutory log grade rules for hemlock and balsam[4] (British Columbia Ministry of Forests, 1999).

Logs were diagrammed to record the size and location of all knots and knot indicators. As illustrated in Figure 2-1, log diagramming is a process by which the log surface is divided into four quadrants around the circumference, and the size and location of all knots, knot indicators, scars, spiral grain and other quality indicators are measured and recorded. Knot diameters were measured inside bark to the nearest 0.5 cm.

The ends of each log were diagrammed to record shake, checks, splits, voids, decay, incipient decay and mechanical damage. Log end diameters were measured to the nearest millimetre to permit accurate size classification. A total of 483 long logs were diagrammed.

Following diagramming, long logs were bucked to short lengths (4.2 m) consistent with Japanese market requirements. This produced a total of 1273 short logs. Two juvenile wood zones represented by the first 15, and first 30 annual rings were identified and marked on the ends of each short log and the diameters of these zones were recorded. The short logs were sorted into two size groups for sawmill conversion: logs less than, and logs larger than or equal to 25 cm small-end diameter.

Log diagramming and the juvenile wood zones marked on log ends are illustrated in Plate II.

Sawmill Conversion

The large log sample was converted to lumber[5]. Table 2-1 shows the volumes from each sample location that were sawn, and the volumes not sawn. Nearly half of the combined sample logs from the three stands were converted to lumber. Because it had the largest trees, approximately 82% of the PH580 log volume was sawn, as compared to only 61% of the PH930 volume, and 58% of the PR930 volume. Figure 2-2 shows how small and large log volumes obtained

---

[3] $V = (tr^2 + br^2) \times L \times 1.570796 \times 10^{-4}$

Where V = log volume (m^3); tr = log top end radius (cm); br = log butt end radius (cm); L = log length (m).

[4] The BC Ministry of Forests uses "balsam" to describe the true firs. In coastal BC amabilis (Abies amabilis (Dougl.) Forbes) is the predominant true fir.

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Plate II

a) Log Diagramming

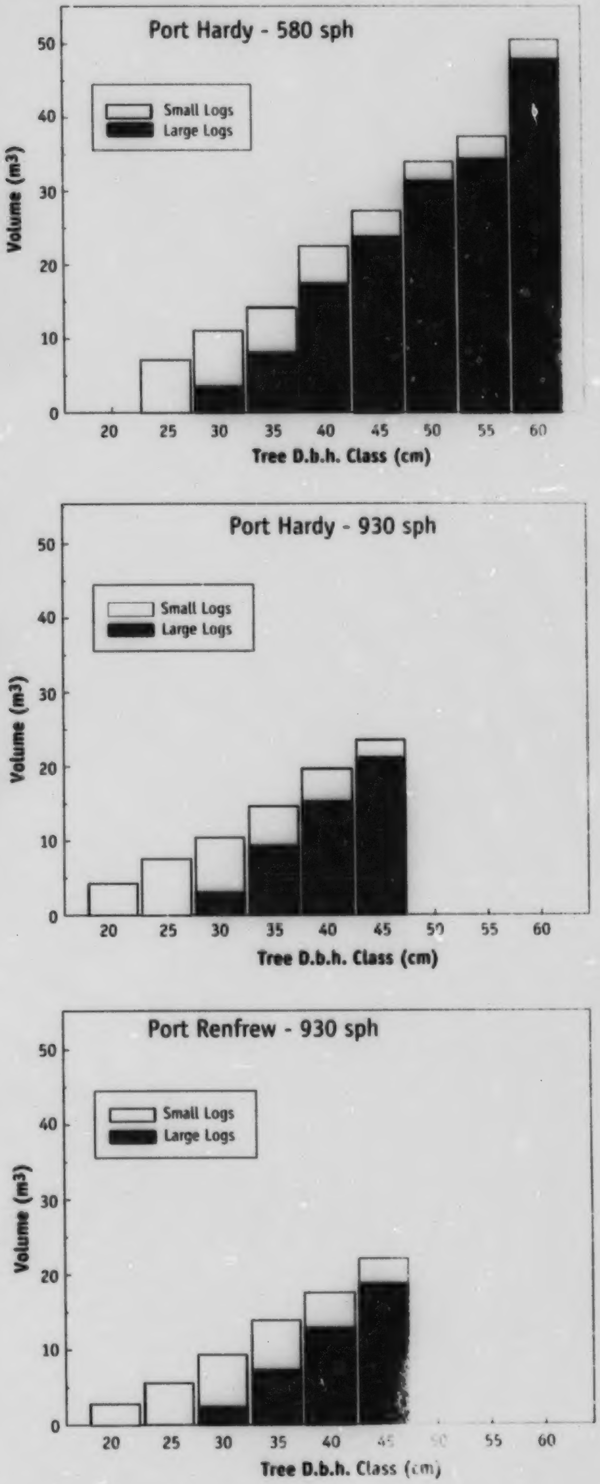
b) Juvenile Wood on Logs Ready for Sawmilling

Table 2-1 *Sawlog Distribution by Tree Sample and Log Size Class*

Size Class	PH580		PH930		PR930	
	No. of Logs	Scale m^3	No. of Logs	Scale m^3	No. of Logs	Scale m^3
< 25 cm	230	36.9	225	31.0	203	29.3
≥ 25 cm	351	166.6	140	48.7	124	41.5
Total	581	203.5	365	79.7	327	70.8

Figure 2-2

Proportions of Log Volumes (Large Logs) Converted to Lumbe



Port Hardy - 580 sph

Port Hardy - 930 sph

Port Renfrew - 930 sph

---

[5] It was intended that all logs be converted to lumber, but cooperating sawmill companies withdrew from the study due to poor economic conditions which precipitated mill closures. Following prolonged delays with an alternative company, the large log sort was sawn at a custom-cutting sawmill. The timely cooperation of a suitable small log sawmill could not be obtained, and the smaller logs were left unsawn.

+3

Plate II

a) Log Diagramming

b) Juvenile Wood on Logs Ready for Sawmilling

[illegible] *Sawlog Distribution by Tree Sample and Log Size Class*

Size Class	PH580		PH930		PR930	
	No. of Logs	Scale m³	No. of Logs	Scale m³	No. of Logs	Scale m³
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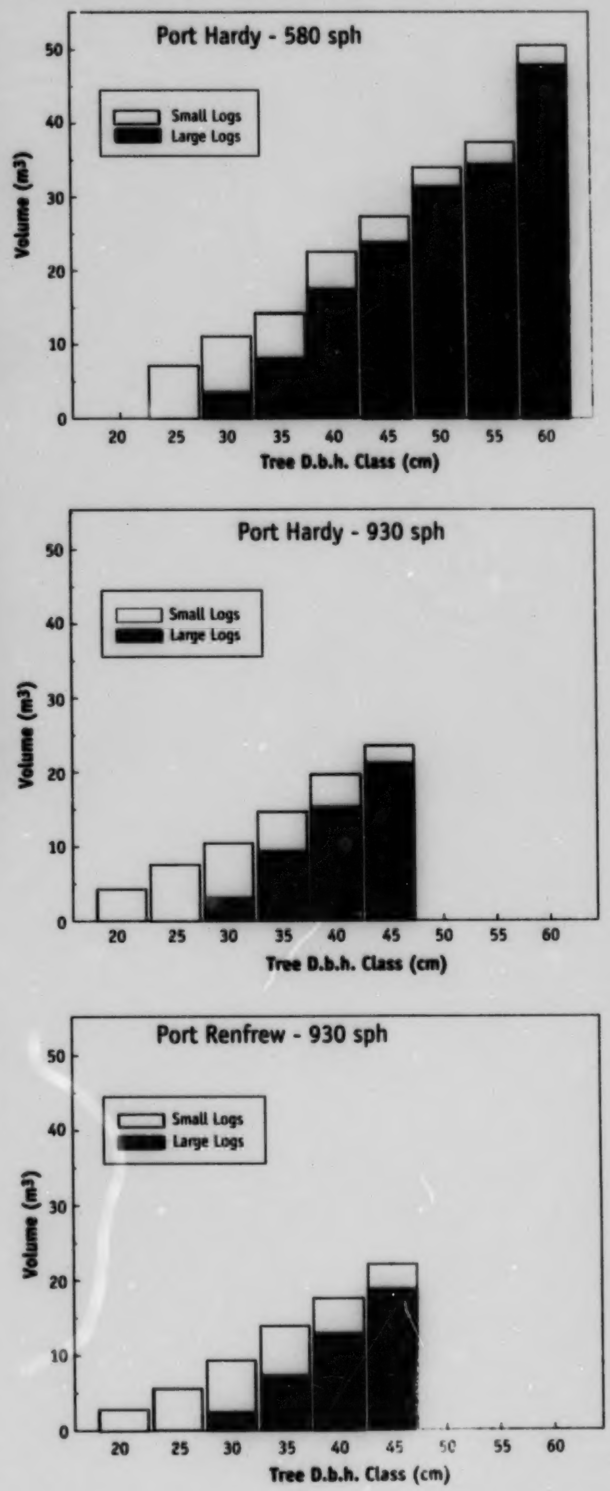
≥ 25 cm	351	166.6	140	48.7	124	41.5
Total	581	203.5	365	79.7	327	70.8

Figure 2-2

Proportions of Log Volumes (Large Logs) Converted to Lumber



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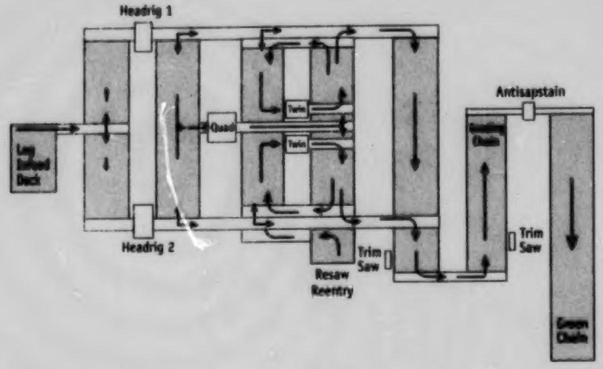
[5] It was intended that all logs be converted to lumber, but cooperating sawmill companies withdrew from the study due to poor economic conditions which precipitated mill closures. Following prolonged delays with an alternative company, the large log sort was sawn at a custom-cutting sawmill. The timely cooperation of a suitable small log sawmill could not be obtained, and the smaller logs were left unsawn.

+3

Figure 2-3
Sawmill Schematic



from each of the three stands were distributed by tree d.b.h. class.

The sawmill used for the conversion study was designed for the purpose of cutting to Japanese specifications, and was equipped with Japanese manufactured sawing equipment. The sawmill had no scanning or optimization equipment. A schematic of the mill is provided in Figure 2-3.

Sample logs were fed into the mill in batches of five, and were colour-coded to keep track of their sequence. Two bandsaw headrigs were used simultaneously, but all lumber coming off the headrigs was fed through the quad band and through only one of the twin bands. This produced a single flow of lumber to staff responsible for keeping track of the mill sequence. Trim saws were used only to remove severe wane (fish tails) so that the juvenile wood markings on log ends would not be removed. Each piece of lumber produced was numbered with the appropriate log sequence number. All lumber was coated with an anti-sapstain solution.

Sawing patterns were chosen[6] for maximum recovery of 105x105 mm dressed, dry squares with 90x90 mm squares to be used as a small log recovery option. These are structural components in traditional Japanese post and beam houses. Two thicknesses, 45 mm and 36 mm, were chosen as alternatives to maximize recovery from side cuts. Side-cut lumber was sawn to random widths in increments of 10 mm. This was the mill's normal practice when cutting Japanese sizes. Green lumber target sizes were calculated using the shrinkage and planer allowances shown in Table 2-2.

Kiln Drying and Planing

Lumber was kiln dried in commercial kilns using moderate schedules to avoid case hardening. Target moisture content was 19 percent for square material, and 15 percent for smaller thicknesses. Following drying, side-cut lumber was sorted into the following 5 widths for planing: 60, 90, 105, 140 and 190 mm. Forty-six pieces of lumber, too wide for the widest sort (190 mm), were planed on the wide surfaces only (S2S). Identification tags were attached to the ends of each lumber piece.

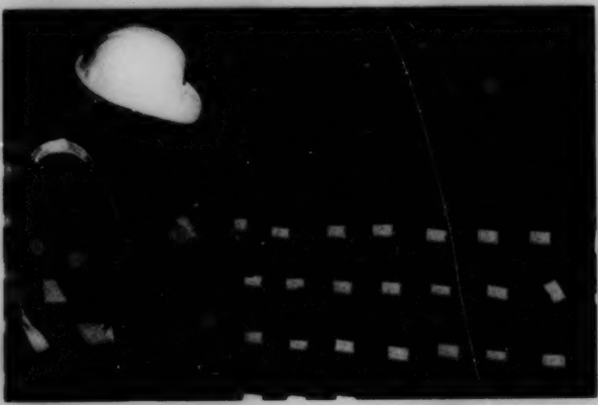
[illegible] *Sawing Allowance*

Final Dry Size	Shrinkage Allowance	Planer Allowance	Green Target
		mm	
90	5	5	100
105	6	5	116
45	2	5	52
36	2	5	43

Plate III illustrates the test lumber being tagged, and the lumber ready for planing. The juvenile wood zones marked on the logs remained readily visible on the ends of each piece.

PLATE III

a) Affixing Identification Tags



b) Lumber Ready for Planing

---

[6] Following Wilson, B. 1989. COFI. Market research in Japan. Report Number 5. p. 52 which describes lumber mainly cut as 105mm and 90mm squares with side cuts of 45mm and 36mm.

Lumber Grading

The sample lumber was graded by a qualified lumber grader according to the Standard Grading Rules for Canadian Lumber for Structural Light Framing (par. 124) and Structural Joists and Planks (par. 124) (NLGA, 1998). It was also graded according to the Japanese Agricultural Standard for Structural Softwood Lumber rules, JAS 143 for Type A Structural Lumber (bending) (JETRO, 1991). In addition, separate grades were determined for each rule based on consideration of knots only.

Because the lumber was not trimmed in the sawmill in order to preserve the juvenile wood markings, some pencil trimming was required during grading. Lumber was pencil trimmed when graded to JAS rules if this raised the grade of the piece from reject to a merchantable grade. It was pencil trimmed under NLGA rules if this raised the grade of the piece from Reject, Economy, or No. 3, to No. 2 Structural or Better.

Grade determining defects were recorded.

The proportion of juvenile wood by volume present in each piece of lumber was estimated, and recorded.

Determining Breast-height Wood Density

Breast-height increment cores were air-dried and cut to a uniform thickness of 1.57 mm on a twin-blade microsaw. These were then extracted in a Soxhlet apparatus in alcohol-cyclohexane (1:2 by volume) for 24 hours, and in hot water for a further 24 hours. The extractive-free radial strips were air-dried to approximately 8 percent equilibrium moisture content. Using a microscope where necessary, the radial strips were marked with calendar year dates and a starting position for pith-to-bark x-ray scanning. The samples were then scanned on Forintek's Direct Reading X-Ray Densitometer (Jozsa and Myronuk, 1986). The densitometer measures ring density in increments of 0.0254 mm (0.001 inch).

4 Results and Discussion

Characteristics of Sample Trees

Summary statistics descriptive of the three tree samples are provided in Table 2-3. Port Hardy trees proved to be somewhat younger than those at Port Renfrew, averaging 82 years total age compared to 88 years. The comparatively higher site index[7] of the PH580 stand would have contributed to the more rapid growth rate which resulted in trees 60 cm d.b.h. and larger.

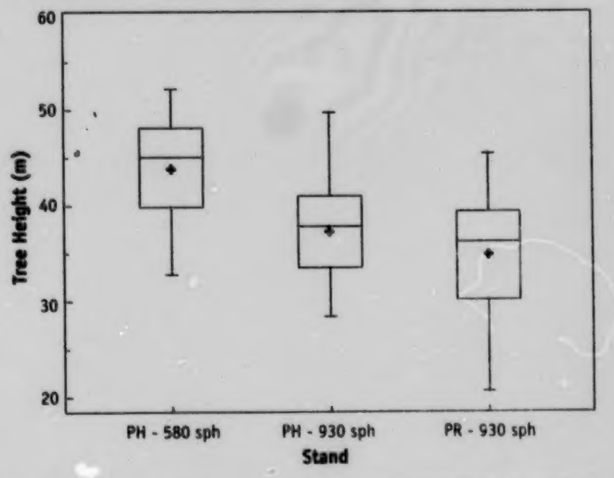
Table 2-3 *Stand and Tree Sample Summary Statistics*

Characteristic	PH580	PH930	PR930
Number of Trees	80	60	60
Stand density (sph)	583	930	932
Site index (b.h. Age 50)	39	32	30
Mean breast-height age	78	77	83
Mean total age	82	82	88
Mean tree height (m)	43.8	37.3	34.9
Mean D.b.h. (cm)	42.7	32.8	32.5
Mean ht. to crown (m)	25.4	24.5	21.3
Mean taper (cm/m)	0.95	0.87	0.92
Mean Crown Ratio (%)	41.9	33.7	38.6

The PH580 stand had the tallest trees followed by PH 930. PH580 had a higher ratio of live crown to tree height when compared to the PH930 stand, but not significantly so when compared to PR930. Tree taper was highest in the PH580 sample, but was also comparatively high in the trees from PR930.

Box chart[8] comparisons of tree heights, heights to base of live crowns and crown ratios are provided in Figures 2-4, 2-5 and 2-6. Box charts comparing tree taper distributions are shown in Figure 2-7.

Figure 2-4
Comparative Distributions of Tree Height



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[7] Site index at breast-height age 50 years based on age and height of the largest trees. Site index was calculated using Site Tools for Windows Version 3.1 (BC Ministry of Forests, 1998) developed from site index tables for western hemlock in the Pacific Northwest (Wiley, 1978).

[8] Box charts provide visual representations of sample distributions. The bottom and top of the box indicate 25th and 75th percentiles respectively. The horizontal line within the box indicates the sample median, and the "+" sign indicates the mean. The vertical lines extending from the box represent the range of the data to a maximum of 1.5 times the interquartile range (box height). Outliers are depicted as separate points.

Figure 2-3
Sawmill Schematic

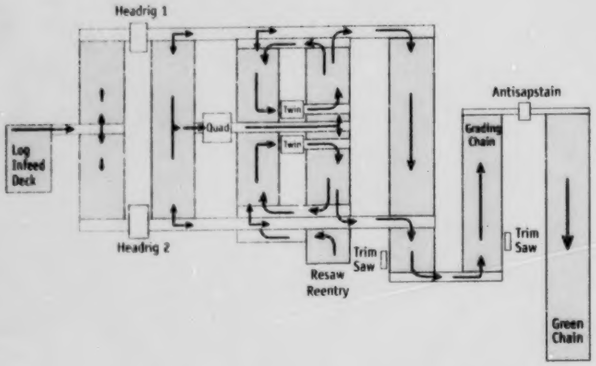

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Table 2-2 *Sawing Allowance*

Final Dry Size	Shrinkage Allowance	Planer Allowance	Green Target
		mm	
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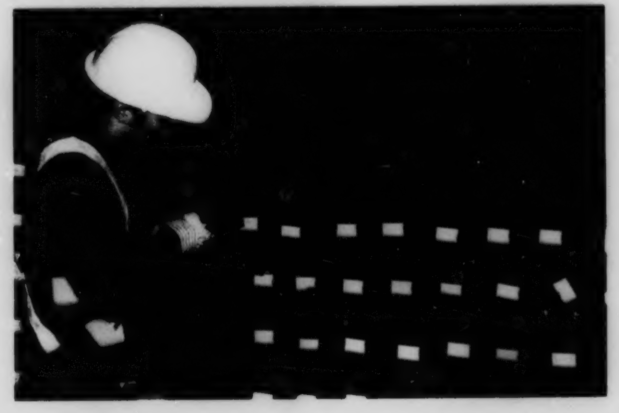
105	6	5	116
45	2	5	52
36	2	5	43

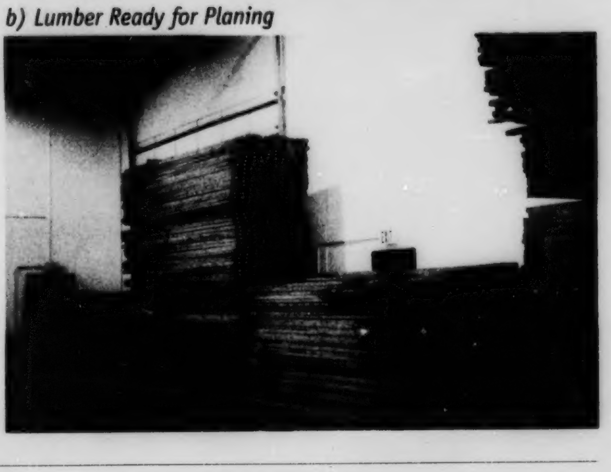
Plate III illustrates the test lumber being tagged, and the lumber ready for planing. The juvenile wood zones marked on the logs remained readily visible on the ends of each piece.

PLATE III

a) Affixing Identification Tags



b) Lumber Ready for Planing



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[6] Following Wilson, B. 1989. COFI. Market research in Japan. Report Number 5. p. 52 which describes lumber mainly cut as 105mm and 90mm squares with side cuts of 45mm and 36mm.

Lumber Grading

The sample lumber was graded by a qualified lumber grader according to the Standard Grading Rules for Canadian Lumber for Structural Light Framing (par. 124) and Structural Joists and Planks (par. 124) (NLGA, 1998). It was also graded according to the Japanese Agricultural Standard for Structural Softwood Lumber rules, JAS 143 for Type A Structural Lumber (bending) (JETRO, 1991). In addition, separate grades were determined for each rule based on consideration of knots only.

Because the lumber was not trimmed in the sawmill in order to preserve the juvenile wood markings, some pencil trimming was required during grading. Lumber was pencil trimmed when graded to JAS rules if this raised the grade of the piece from reject to a merchantable grade. It was pencil trimmed under NLGA rules if this raised the grade of the piece from Reject, Economy, or No. 3, to No. 2 Structural or Better.

Grade determining defects were recorded.

The proportion of juvenile wood by volume present in each piece of lumber was estimated, and recorded.

Determining Breast-height Wood Density

Breast-height increment cores were air-dried and cut to a uniform thickness of 1.57 mm on a twin-blade microsaw. These were then extracted in a Soxhlet apparatus in alcohol-cyclohexane (1:2 by volume) for 24 hours, and in hot water for a further 24 hours. The extractive-free radial strips were air-dried to approximately 8 percent equilibrium moisture content. Using a microscope where necessary, the radial strips were marked with calendar year dates and a starting position for pith-to-bark x-ray scanning. The samples were then scanned on Forintek's Direct Reading X-Ray Densitometer (Jozsa and Myronuk, 1986). The densitometer measures ring density in increments of 0.0254 mm (0.001 inch).

4 Results and Discussion

Characteristics of Sample Trees

Summary statistics descriptive of the three tree samples are provided in Table 2-3. Port Hardy trees proved to be somewhat younger than those at Port Renfrew, averaging 82 years total age compared to 88 years. The comparatively higher site index[7] of the PH580 stand would have contributed to the more rapid growth rate which resulted in trees 60 cm d.b.h. and larger.

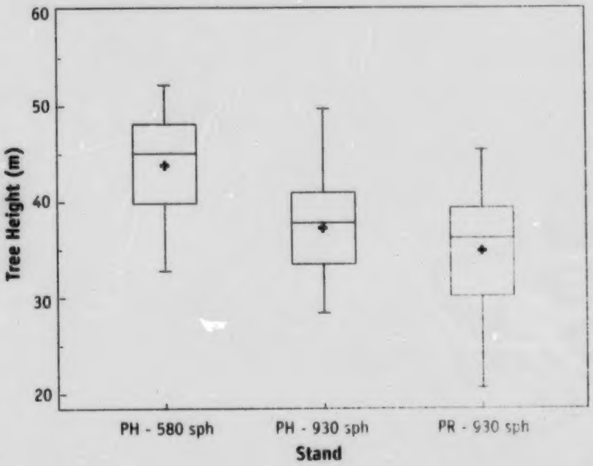
Table 2-3 *Stand and Tree Sample Summary Statistics*

Characteristic	PH580	PH930	PR930
Number of Trees	80	60	60
Stand density (sph)	583	930	932
Site index (b.h. Age 50)	39	32	30
Mean breast-height age	78	77	83
Mean total age	82	82	88
Mean tree height (m)	43.8	37.3	34.9
Mean D.b.h. (cm)	42.7	32.8	32.5
Mean ht. to crown (m)	25.4	24.5	21.3
Mean taper (cm/m)	0.95	0.87	0.92
Mean Crown Ratio (%)	41.9	33.7	38.6

The PH580 stand had the tallest trees followed by PH 930. PH580 had a higher ratio of live crown to tree height when compared to the PH930 stand, but not significantly so when compared to PR930. Tree taper was highest in the PH580 sample, but was also comparatively high in the trees from PR930.

Box chart[8] comparisons of tree heights, heights to base of live crowns and crown ratios are provided in Figures 2-4, 2-5 and 2-6. Box charts comparing tree taper distributions are shown in Figure 2-7.

Figure 2-4
Comparative Distributions of Tree Height



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[7] Site index at breast-height age 50 years based on age and height of the largest trees. Site index was calculated using Site Tools for Windows Version 3.1 (BC Ministry of Forests, 1998) developed from site index tables for western hemlock in the Pacific Northwest (Wiley, 1978).

[8] Box charts provide visual representations of sample distributions. The bottom and top of the box indicate 25th and 75th percentiles respectively. The horizontal line within the box indicates the sample median, and the "+" sign indicates the mean. The vertical lines extending from the box represent the range of the data to a maximum of 1.5 times the interquartile range (box height). Outliers are depicted as separate points.

Figure 2-5
Comparative Distributions of Height to Base of Live Crown

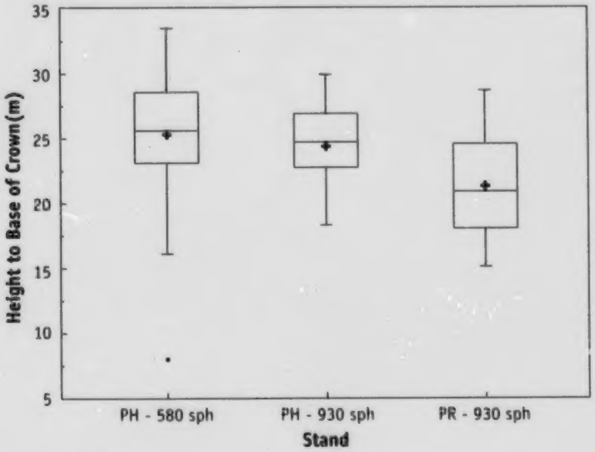


Figure 2-6
Comparative Distributions of Crown Ratios

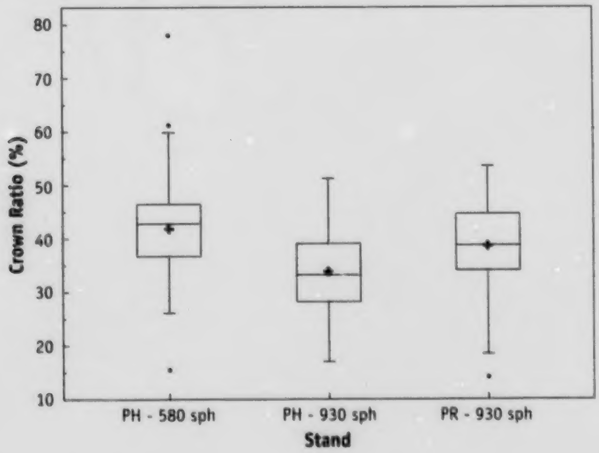
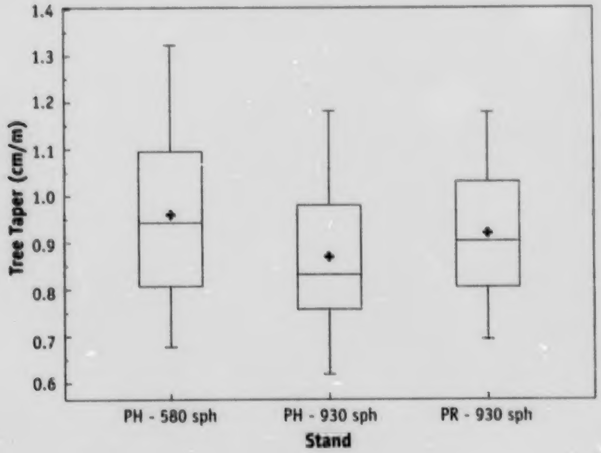


Figure 2-7
Comparative Distributions of Tree Taper



Distributions of sample trees by height and d.b.h. are compared for the tree stands in Figure 2-8. The figure illustrates that trees at PH580 generally grew taller across the diameter range, and that those at PR930 were generally the shortest.

Table 2-4 provides comparative stand distributions of the tree quality and pathological indicators that were recorded. Sweep was recorded in nearly a third of the trees on all three stands. Lean was present to a lesser degree, and was most prevalent at PH930. Western hemlock is shallow rooted and prone to windfall, and all three stands were exposed to severe wind. Stem instability and growth correction could explain the incidence of sweep and lean. It must be noted, however, that with the exception of 2 trees with greater lean at PH930, all of the sweep and lean was recorded as minor (5 to 10° from vertical). Spiral grain was present in a minor percentage of trees at PH580.

The sample locations were chosen to be generally free of pathogens (in particular dwarf mistletoe, *A. tsugense* (Rosendahl) G. N. Jones) to avoid their possible confounding influence on relationships between tree growth and wood quality attributes. Scarring was the only pathological

Figure 2-8
Distribution of Sample Trees by Height and D.b.h.

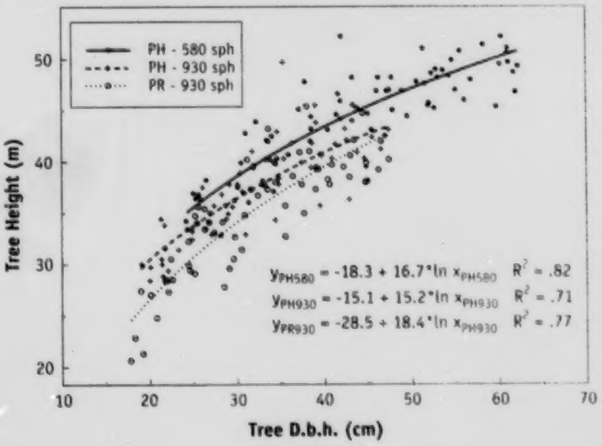


Table 2-4 *Occurrence of Tree Pathological and Quality Indicators*

Tree Indicator	PH580	PH930	PR930
	% of Trees		
Sweep	31.3	30.0	28.3
Lean	3.8	11.7	5.0
Closed Scar	30.0	16.7	1.7
Spiral Grain	2.5	0.0	0.0

Figure 2-5
Comparative Distributions of Height to Base of Live Crown

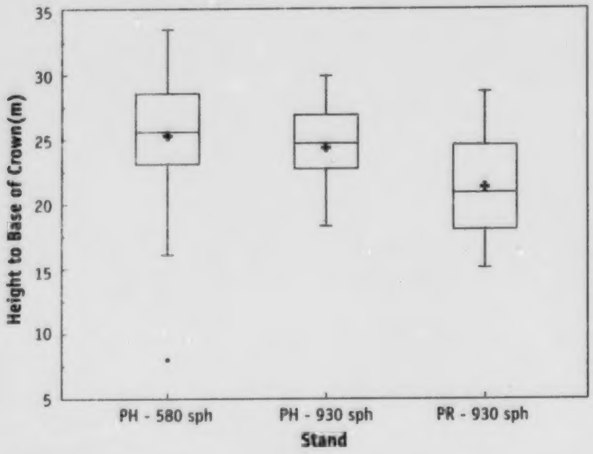


Figure 2-6
Comparative Distributions of Crown Ratios

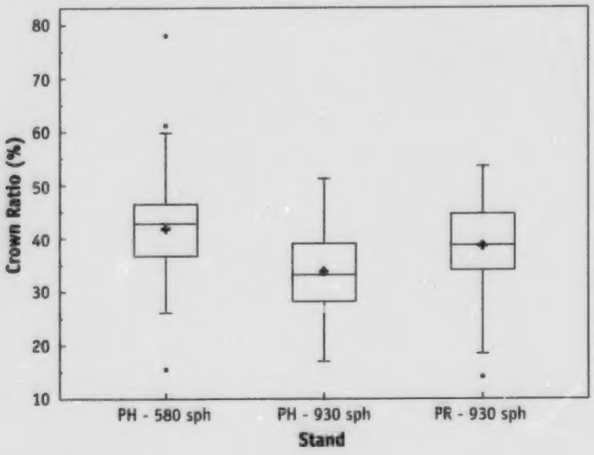
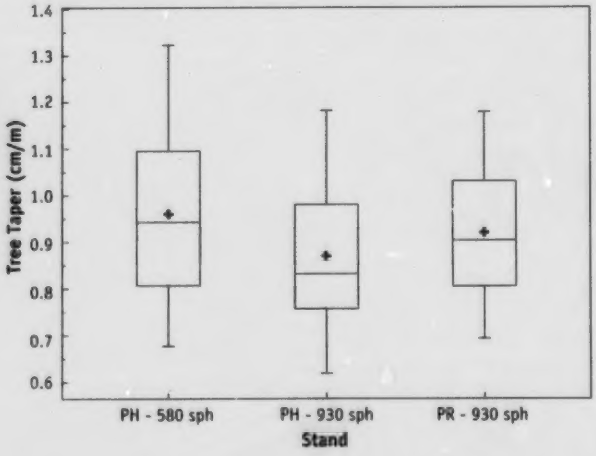


Figure 2-7
Comparative Distributions of Tree Taper



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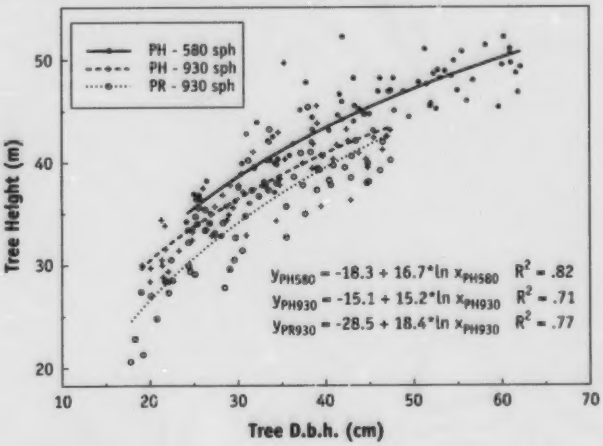

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Lean	3.8	11.7	5.0
Closed Scar	30.0	16.7	1.7
Spiral Grain	2.5	0.0	0.0

indicator present in the sample trees. Scars were most prevalent at the Port Hardy locations and the majority of these were "catface" located at the base of the tree. Few scars were recorded at PR930.

Wood Density

The average basic relative density of western hemlock wood has been variously reported to be 0.409 (Jessome, 1977), .423 (Smith, 1970) and .427 (Kennedy and Swann, 1969). A survey of 1040 trees in the Pacific Northwest by the United States Forest Service (U.S. Forest Service, 1965) put the whole-stem average at .421 with a range of .300 to .520, and the generally accepted species average stemwood density for western hemlock is .42. In western hemlock, however, wood density declines with increasing tree height, and at breast-height the average is .447.[9]

Mean breast-height wood density values for the three tree samples in this study were .422, .446 and .473 for PH580, PH930 and PR930 respectively. These mean values were significantly different at the .0001 level. Compared on the basis of breast-height values the average density of PH580 trees is lower than the species average value, the average density of PH930 trees essentially equal it, and the average density of PR930 trees exceed it. Box plots of breast-height density distributions are shown in Figure 2-9. Pith-to-bark density trends are compared for all trees in Figure 2-10, and for the range of d.b.h. classes they have in common (25-45 cm) in Figure 2-11.

The pith-to-bark trend in average wood density for PR930 trees has only a brief and shallow juvenile zone depression. The minimum falls below average breast-height density of the species between 10 and 15 annual rings from the pith. A point of inflection, sometimes used to mark the end of the juvenile wood period, occurs at approximately cambial age 20.

The pith-to-bark average density trends for PH930 and PH580 trees exhibit much lower and more prolonged juvenile wood depressions. Minimum average values are well below the species average wood density. Inflection points which could mark the end of the juvenile wood zones are at about 25 and 30 years respectively. Pith-to-bark average density trends for the two Port Hardy stands show very similar patterns, but the PH580 trend begins lower, has a lower minimum and remains below the PH930 trend line until, when large d.b.h. classes are excluded, about cambial age 40 (Figure 2-11).

A survey of 29 trees with a mean age of 133 and range of 96 to 186 years sampled in Alaska resulted in an average of

Figure 2-9
Comparative Breast-height Wood Density Distributions

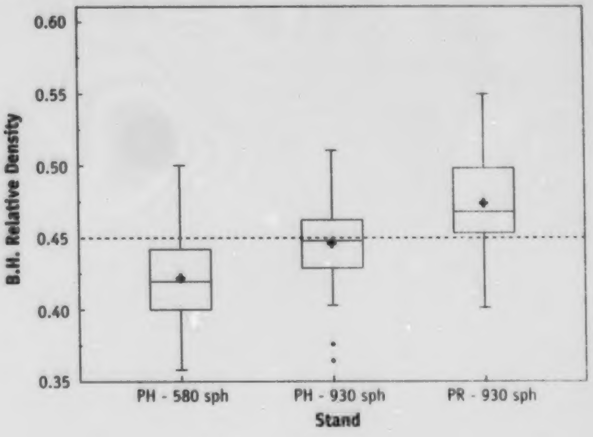


Figure 2-10
Stand Comparison of Pith-to-Bark Density Trends for All Trees

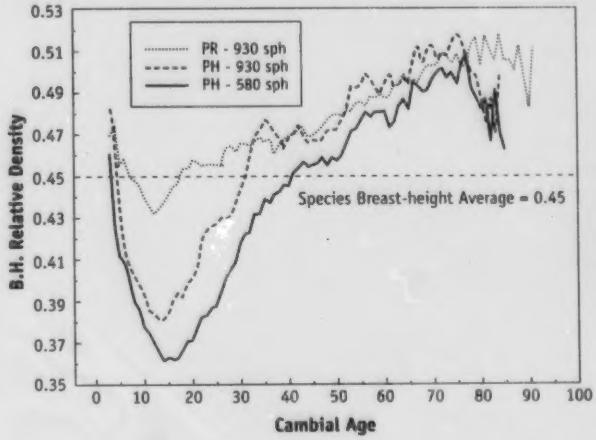
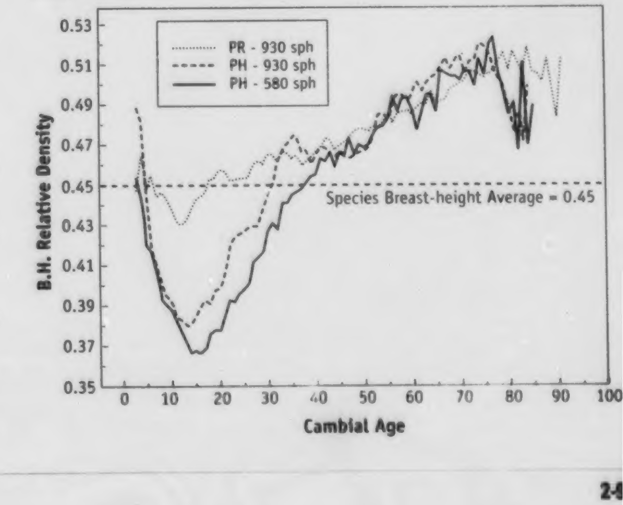


Figure 2-11
Comparison of Pith-to-Bark Density Trends for Common D.b.h. Class Trees



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[9] The value of .447 was derived by volume weighting the breast-height density values recorded for the 1040 trees in the U.S. Forest Service study in the same manner they used to determine their whole-tree species average.

.399 and range of .370 to .444 (Farr, 1973). The fact that the wood density of trees sampled here exceeds that of older trees in Alaska is consistent with observations about northern lodgepole pine (Middleton and Munro, 2000) and hypotheses about northern site Scots pine (*Pinus sylvestris* L.) (Jonsson and Persson, 1996).

A through consideration of wood density trends in second-growth western hemlock from these stands was provided by Jozsa *et al.* (1998). In this study the focus was on how wood density was related to growth rate, which foresters can manipulate through stand density management.

Growth Rate and Wood Density

Table 2-5 provides comparative wood density and basal area values for the first 15, and first 30 years of growth. The relationship between wood density and early basal area growth rate was as expected, with lowest mean density associated with the fastest grown trees at PH580, and the highest mean density found at PR930 where early growth rate was slowest. Mean density values for the first 15 and 30 annual rings reveal that the density of the PR930 trees was considerably higher than that of the Port Hardy trees to 15 years and 30 years.

Differences in early growth rate can be attributed to differences in site and differences in initial stand density. The latter cannot be quantified for the natural stands sampled in this study, and differences in early growth rate between sites remain inherent in any measure of site influence.

Figure 2-12 shows annual ring widths compared for all trees in each stand. The larger trees obtained at PH580 inflate the early growth rates at that location. At 15 years of age, the faster early growth of the larger tree size classes at PH580 resulted in average annual rings that were more than two times wider than those at PR930.

Table 2-5 *Early Breast-height Basal Area Growth Rates and Comparative Wood Density*

Breast-height Measure	PH580	PH930	PR930
Mean Density Of 1st 15 rings	.373	.388	.438
Mean % Basal Area In 1st 15 Rings	14.4	15.7	8.7
Mean Density Of 1st 30 Rings	.379	.405	.447
Mean % Basal Area In 1st 30 Rings	46.4	44.9	25.7
Mean Density	.422	.446	.473

Figure 2-12

Annual Ring Width by Cambial Age Compared for All Trees

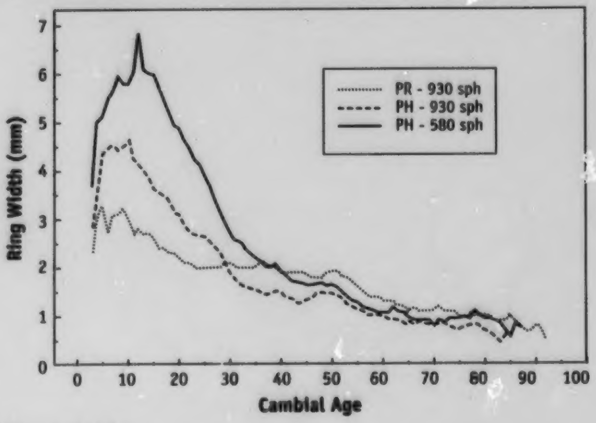


Figure 2-13

Annual Ring Width Compared for Trees of Common Tree D.b.h. Classes

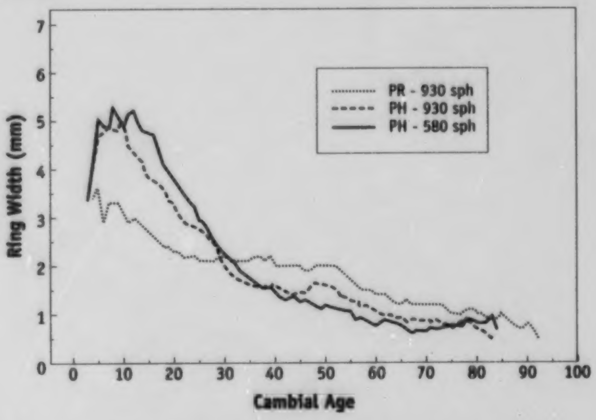


Figure 2-13 provides the same comparison of annual ring width as above, but is restricted to trees of the same breast-height diameter classes (25 – 45 cm). Notice that at approximately age 15 the average annual ring width of the PH580 trees (between 4.5 and 5.0 mm) remains nearly double that of the PR930 trees indicating that fast early growth was common to all PH580 trees. This lead in annual growth rate persisted to 30 years, but by age 40 PH580 trees produced narrower annual rings than the trees on the other two stands.

Annual average cambial growth rates at the two Port Hardy stands show nearly identical patterns of fast early growth followed by a steep decline. Port Renfrew trees grew more slowly and show a decline in growth rate to age 20 after which ring width averaged a nearly constant 2 mm per year until age 50. This plateau in the trend, which suggests some natural release event, resulted in PR930 trees taking the lead in annual ring width and retaining it to the present.

Figure 2-14 shows average trends in tree diameter growth by cambial age for trees of the same d.b.h. range. Diameter

Figure 2-14

Average Tree Diameter Growth Compared for Trees of Common D.b.h. Class

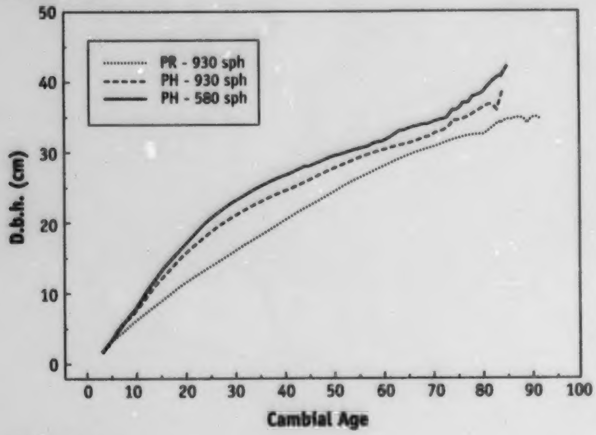
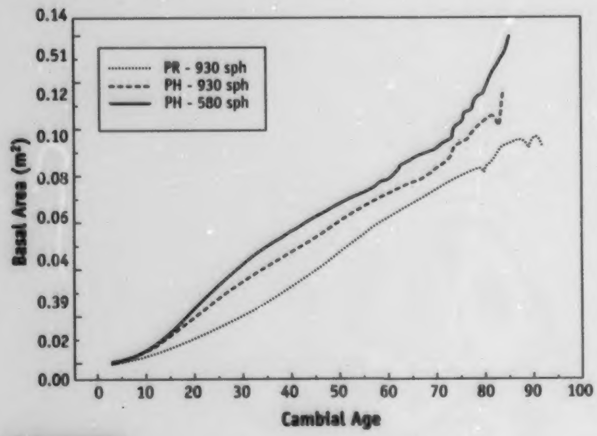


Figure 2-15

Average Tree Basal Area Growth Compared for Trees of Common D.b.h. Class



growth at PR930, began at a slower pace and remained nearly constant thereafter. Trees at the two Port Hardy locations grew more rapidly in diameter to 30 years after which rate-of-growth declined relative to the PR930 stand.

Figure 2-15 compares tree average basal area growth for trees of the same d.b.h. classes. Basal area growth was most constant at PH930, began slow and increased to a constant rate at PR930, and began fast then declined slightly at PH580.

Knots and Knot Indices

Table 2-6, derived from log diagramming data, provides the number and size of knots per log recorded for each log sample. The table shows that logs from PH580 trees had the highest mean knot frequencies and the largest mean and maximum knot sizes. This is consistent with the comparatively lower stand density and larger tree diameters. Mean knot size was not significantly different between the PH930 and PR930 samples. Mean knot size for the PH580 sample was significantly larger. Logs from the PH930 stand had the smallest maximum knot size.

Measuring all knots in logs, or all accessible branches[10] in standing trees is not operationally practical, and researchers (Sutton, 1984; Middleton and Munro, 1989; Middleton *et al*, 1995) have investigated the use of various knot indices to predict the effect of branch size on lumber grade yields.

Table 2-7 provides statistics for the following knot indices considered in this study:

- average size of the four largest knots per log (AVGL4);
- average size of the largest knot in each log quadrant

Table 2-6 *Knot Statistics*

Log Sample	Number of Knots Per Log			Size of Knots Per Log (cm)		
	mean	min	max	mean	min	max
PH580	75	2	246	1.5	0.6	3.2
PH930	74	1	192	1.2	0.6	3.2
PR930	65	4	169	1.2	0.5	2.2

Table 2-7 *Knot Indices*

Log Semple	Average Size of Four Largest Knots Per Log (cm)			Average Size of Largest Knot in Each Log Quadrant (cm)			Average Size of Largest Knot Per Log (cm)		
	min	max	mean	min	max	mean	min	max	mean
PH580	3.0	1.0	7.5	2.7	0.3	6.8	3.4	1.0	8.0
PH930	2.3	0.8	4.8	2.1	0.3	4.1	2.6	1.0	5.0
PR930	2.5	0.5	5.5	2.1	0.4	5.4	2.9	0.5	6.5

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[10] Knot measurements are considered to be equivalent to branch size measurements when both are measured on the same basis with respect to bark. Branch sizes, however, are generally measured more accurately by using a caliper to 0.5 mm.

.399 and range of .370 to .444 (Farr, 1973). The fact that the wood density of trees sampled here exceeds that of older trees in Alaska is consistent with observations about northern lodgepole pine (Middleton and Munro, 2000) and hypotheses about northern site Scots pine (*Pinus sylvestris* L.) (Jonsson and Persson, 1996).

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Growth Rate and Wood Density

Table 2-5 provides comparative wood density and basal area values for the first 15, and first 30 years of growth. The relationship between wood density and early basal area growth rate was as expected, with lowest mean density associated with the fastest grown trees at PH580, and the highest mean density found at PR930 where early growth rate was slowest. Mean density values for the first 15 and 30 annual rings reveal that the density of the PR930 trees was considerably higher than that of the Port Hardy trees to 15 years and 30 years.

Differences in early growth rate can be attributed to differences in site and differences in initial stand density. The latter cannot be quantified for the natural stands sampled in this study, and differences in early growth rate between sites remain inherent in any measure of site influence.

Figure 2-12 shows annual ring widths compared for all trees in each stand. The larger trees obtained at PH580 inflate the early growth rates at that location. At 15 years of age, the faster early growth of the larger tree size classes at PH580 resulted in average annual rings that were more than two times wider than those at PR930.

Table 2-5 *Early Breast-height Basal Area Growth Rates and Comparative Wood Density*

Breast-height Measure	PH580	PH930	PR930
Mean Density Of 1st 15 rings	.373	.388	.438
Mean % Basal Area In 1st 15 Rings	14.4	15.7	8.7
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Mean Density	.422	.446	.473

Figure 2-12
Annual Ring Width by Cambial Age Compared for All Trees

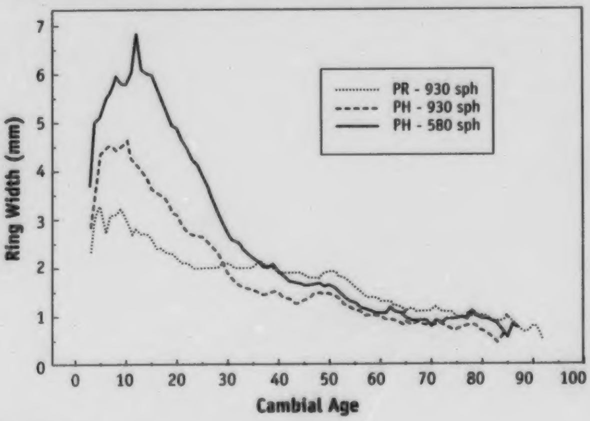

Figure 2-13
Annual Ring Width Compared for Trees of Common Tree D.b.h. Classes

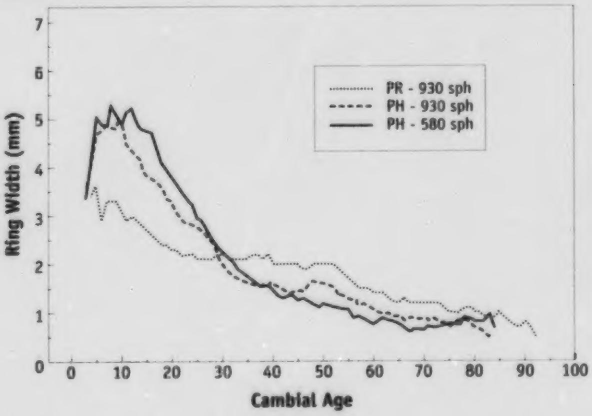

Figure 2-13 provides the same comparison of annual ring width as above, but is restricted to trees of the same breast-height diameter classes (25 – 45 cm). Notice that at approximately age 15 the average annual ring width of the PH580 trees (between 4.5 and 5.0 mm) remains nearly double that of the PR930 trees indicating that fast early growth was common to all PH580 trees. This lead in annual growth rate persisted to 30 years, but by age 40 PH580 trees produced narrower annual rings than the trees on the other two stands.

Annual average cambial growth rates at the two Port Hardy stands show nearly identical patterns of fast early growth followed by a steep decline. Port Renfrew trees grew more slowly and show a decline in growth rate to age 20 after which ring width averaged a nearly constant 2 mm per year until age 50. This plateau in the trend, which suggests some natural release event, resulted in PR930 trees taking the lead in annual ring width and retaining it to the present.

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Figure 2-14
Average Tree Diameter Growth Compared for Trees of Common D.b.h. Class

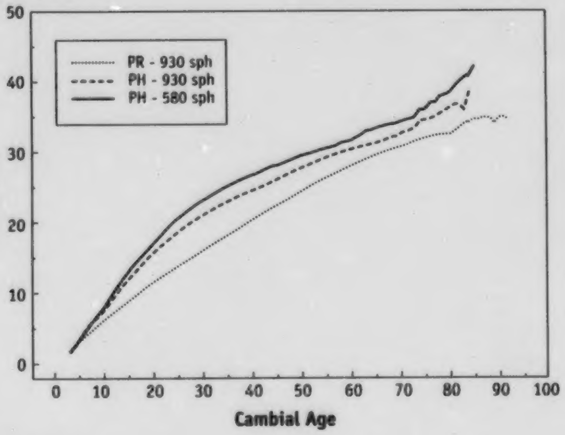
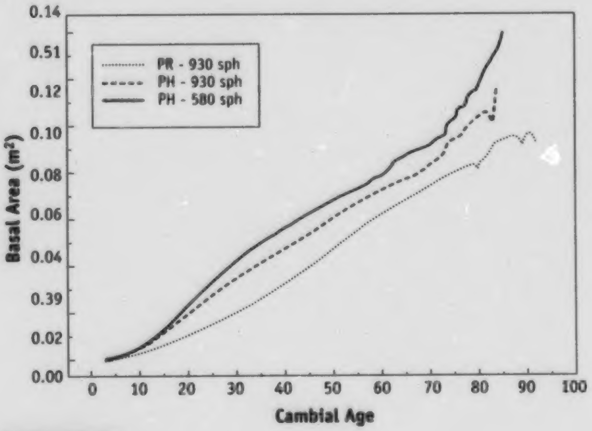


Figure 2-15
Average Tree Basal Area Growth Compared for Trees of Common D.b.h. Class



growth at PR930, began at a slower pace and remained nearly constant thereafter. Trees at the two Port Hardy locations grew more rapidly in diameter to 30 years after which rate-of-growth declined relative to the PR930 stand.

Figure 2-15 compares tree average basal area growth for trees of the same d.b.h. classes. Basal area growth was most constant at PH930, began slow and increased to a constant rate at PR930, and began fast then declined slightly at PH580.

Knots and Knot Indices

Table 2-6, derived from log diagramming data, provides the number and size of knots per log recorded for each log sample. The table shows that logs from PH580 trees had the highest mean knot frequencies and the largest mean and maximum knot sizes. This is consistent with the comparatively lower stand density and larger tree diameters. Mean knot size was not significantly different between the PH930 and PR930 samples. Mean knot size for the PH580 sample was significantly larger. Logs from the PH930 stand had the smallest maximum knot size.

Measuring all knots in logs, or all accessible branches[10] in standing trees is not operationally practical, and researchers (Sutton, 1984; Middleton and Munro, 1989; Middleton *et al*, 1995) have investigated the use of various knot indices to predict the effect of branch size on lumber grade yields.

Table 2-7 provides statistics for the following knot indices considered in this study:

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	min	max	mean	min	max	mean	min	max	mean
PH580	3.0	1.0	7.5	2.7	0.3	6.8	3.4	1.0	8.0
PH930	2.3	0.8	4.8	2.1	0.3	4.1	2.6	1.0	5.0
PR930	2.5	0.5	5.5	2.1	0.4	5.4	2.9	0.5	6.5

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[10] Knot measurements are considered to be equivalent to branch size measurements when both are measured on the same basis with respect to bark. Branch sizes, however, are generally measured more accurately by using a caliper to 0.5 mm.

(AVGQ4); and
- largest knot per log (MAXK).

When compared on the basis of these knot indices, the PH930 sample had the smallest average knot size per log.

Graphic representation of the distribution of these various measures of knot size are compared for each tree sample in Figures 2-16 to 2-19.

Regression analysis was performed to determine estimating equations for percent Select Structural lumber recovery (SS%) based on log top diameter (TOP) and knot indices. The effectiveness of knot indices as estimators is compared below to that of average knot size per log (MEANK).

	R^2
SS% = 110.686 – 0.041 TOP* – 38.855 MEANK	.36
SS% = 117.728 – 0.692 TOP – 15.549 AVGL4	.36
SS% = 112.301 – 0.654 TOP – 15.691 AVGQ4	.33
SS% = 116.612 – 0.711 TOP – 13.191 MAXK	.32

With the exception of top diameter where indicated (*), all parameter estimates were significant at the 0.0001 level.

In two previous studies (Middleton and Munro, 1989; Midddleton, *et al.* 1995) average knot size proved to be the best, albeit weak, predictor of percent Select Structural lumber yield as measured by R^2. Here it remained one of the best, but the average of the four largest knots recorded in each log proved equal. This proxy is useful because although average knot size can be generated in computer models of tree growth, it is not a practical measure to obtain in the field. The R^2 value of .36 obtained for the best predictive equations in this study was identical to that obtained for a similar equation relating percent Select Structural to average knot size and log diameter in lodgepole pine (Middleton *et al.* 1995).

Figure 2-16
Stand Comparisons of Mean Knot Size Per Log

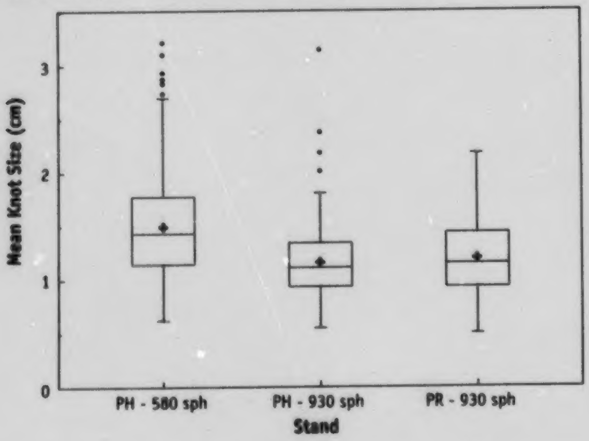


Figure 2-17
Stand Comparisons of Largest Knot Per Log

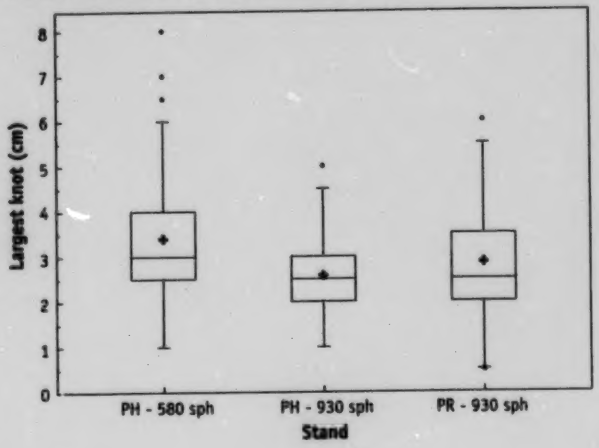


Figure 2-18
Stand Comparisons of Largest 4 Knots Per Log

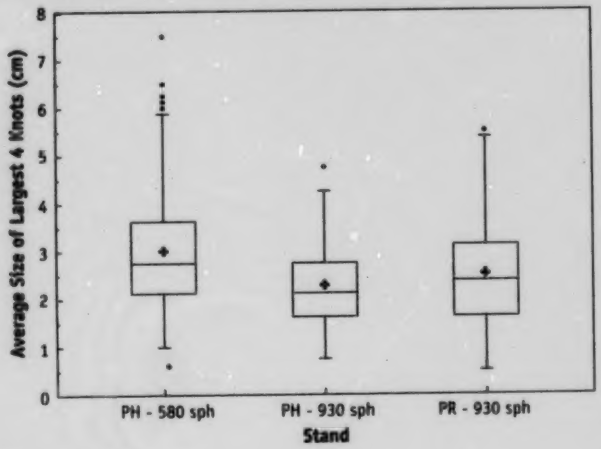
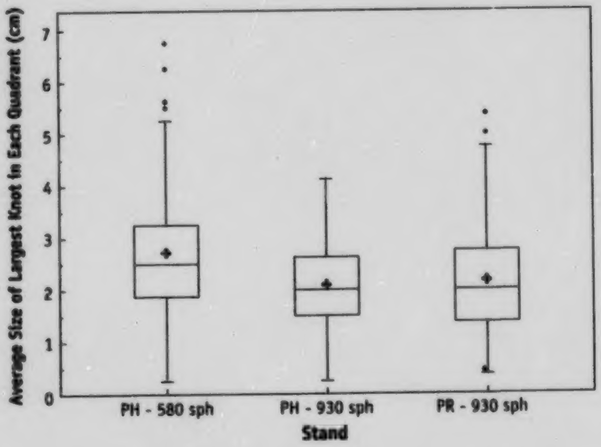


Figure 2-19
Stand Comparisons of Largest Knot In Each Quadrant Per Log



A similar analysis was performed with percent No. 1 JAS grade as the dependent variable. The results are shown below:

	R^2
JAS1% = 18.790 + 0.317 TOP – 13.912 MEANK	.28
JAS1% = 20.898 + 0.087 TOP* – 5.445 AVGL4	.26
JAS1% = 20.672 + 0.087 TOP* – 6.049 AVGQ4	.29
JAS1% = 20.291 + 0.082 TOP* – 4.565 MAXK	.24

With the exception of top diameter where indicated (*), all parameter estimates were significant at the 0.0001 level.

By a slight margin over average knot size, average size of the largest knot in each of the log quadrants (AVGQ4) proved to be the best predictor of JAS No. 1 grade percentage.

The range in R^2 obtained for predictions of both Select Structural and JAS No. 1 grade percentages was identical over the various knot measures. Equations for percent Select Structural "explained" more of the variation having somewhat higher R^2 values for each knot index.

The effect of log top diameter differed by grade rule. When considered in relation to Select Structural grade, the parameter estimates for top diameter were negative. The larger the log, the lower the percent Select Structural. They were significant in all but the equation where top diameter was considered in combination with average knot size. When related to the JAS No. 1 grade percentage, the parameter estimates for log top diameter were positive, larger logs equated to higher proportions of JAS No. 1, but top diameter was not significant except when in combination with average knot size.

Juvenile Wood

The two tentative measures of juvenile wood used in this study were determined entirely on the basis of average pith-to-bark wood density trends, and do not take into consideration other measures of juvenility such as changes in microfibril angle. Pith-to-bark density trends vary considerably from tree to tree, and for individual logs and pieces of lumber these general zones provide weak estimates of the variation in wood strength and stiffness properties (Middleton, et al. 1995).

Tables 2-8a and 2-8b show mean[11] percent juvenile wood proportions by volume distributed by stand and tree d.b.h. classes. These proportions were calculated on the basis of log volume measurements. A consistent trend is evident. Trees from PH580 have the largest proportions of volume contained within both the first 15 and first 30 annual rings, followed by trees from PH930. The PR930 trees have significantly lower proportions of volume contained within these two juvenile wood zones.

Wood scientists generally agree that differences in wood density are much more dependent on cambial age than on growth rate (ring width). However, except where some intervention (a natural event or silvicultural treatment) has increased growth rate at a later age, the most rapid tree growth occurs during the years prior to stand closure. This generally coincides with the period of juvenility, and certainly includes it. Faster growth rate during the juvenile period results in lower average wood density, because it increases the proportion of low-density juvenile wood present in the tree. It has been demonstrated for other B.C. softwoods that lower average wood density reduces the strength and stiffness of solid wood products (Kellogg *et al.*, 1989; Middleton *et al.*, 1995). Proportions of juvenile wood are illustrated in Figure 2-20.

Log Grades

Table 2-9 provides percent log volume distributions by log grades obtained from the sample trees on each of the three stands. The grades are a first order estimate of log value and

Table 2-8a *Percentage of Juvenile Wood – (15 Rings from Pith)*

Tree D.b.h Class (cm)	Stand		
	PH580	PH930	PR930
20	-	33.4	17.8
25	34.5	30.0	18.1
30	31.2	26.4	17.2
35	28.1	21.3	14.7
40	22.5	19.9	13.3
45	21.8	19.3	13.7
50	22.2	-	-
55	19.9	-	-
60	20.4	-	-

Table 2-8b *Percentage of Juvenile Wood – (30 Rings from Pith)*

Tree D.b.h Class (cm)	Stand		
	PH580	PH930	PR930
20	-	74.0	50.8
25	77.5	66.7	48.7
30	71.0	63.5	44.3
35	64.8	53.5	41.8
40	58.6	51.1	40.2
45	54.0	50.7	39.9
50	55.7	-	-
55	53.1	-	-
60	56.3	-	-

---

[11] Calculated for each d.b.h. class as ΣJW Vol / ΣLog Vol * 100

A similar analysis was performed with percent No. 1 JAS grade as the dependent variable. The results are shown below:

	R^2
JAS1% = 18.790 + 0.317 TOP - 13.912 MEANK	.28
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With the exception of top diameter where indicated (*), all parameter estimates were significant at the 0.0001 level.

By a slight margin over average knot size, average size of the largest knot in each of the log quadrants (AVGQ4) proved to be the best predictor of JAS No. 1 grade percentage.

The range in R^2 obtained for predictions of both Select Structural and JAS No. 1 grade percentages was identical over the various knot measures. Equations for percent Select Structural "explained" more of the variation having somewhat higher R^2 values for each knot index.

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40	22.5	19.9	13.3
45	21.8	19.3	13.7
50	22.2	-	-
55	19.9	-	-
60	20.4	-	-

Table 2-8b *Percentage of Juvenile Wood – (30 Rings from Pith)*

Tree D.b.h Class (cm)	Stand		
	PH580	PH930	PR930
20	-	74.0	50.8
25	77.5	66.7	48.7
30	71.0	63.5	44.3
35	64.8	53.5	41.8
40	58.6	51.1	40.2
45	54.0	50.7	39.9
50	55.7	-	-
55	53.1	-	-
60	56.3	-	-

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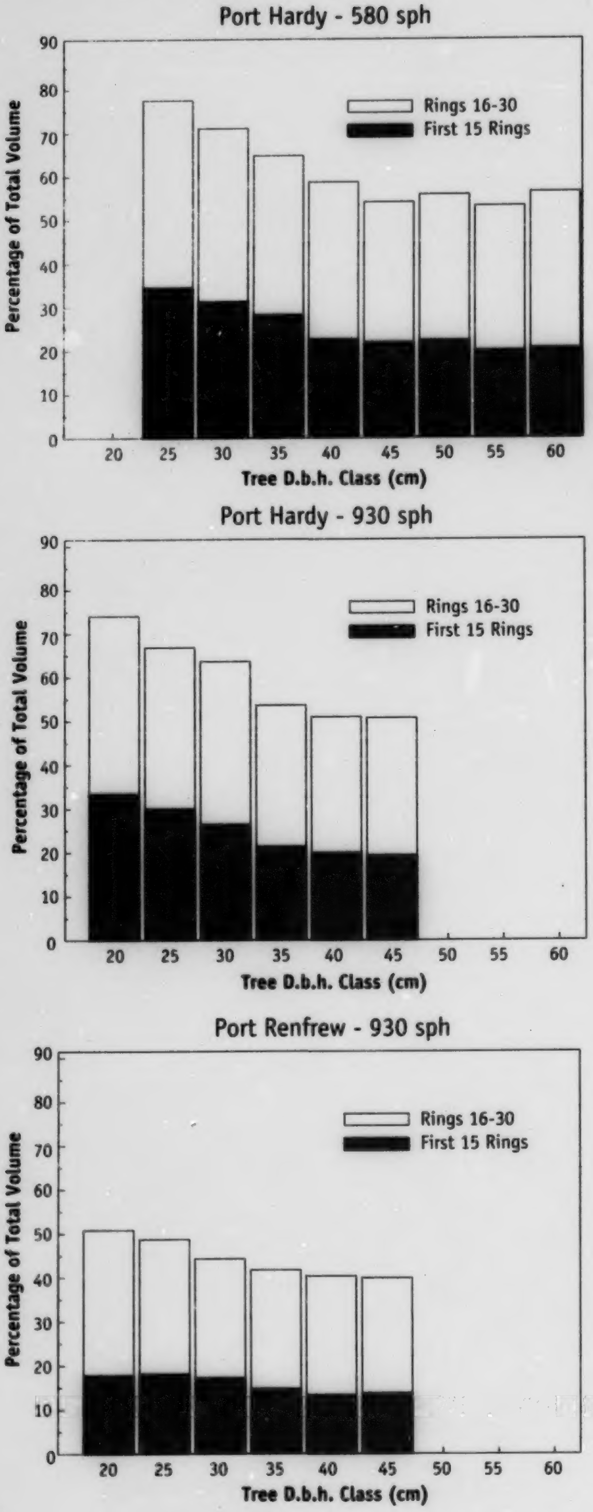
[11] Calculated for each d.b.h. class as ΣJW Vol / ΣLog Vol * 100

Figure 2-20
Proportions of Juvenile Wood


Port Hardy - 580 sph

Port Hardy - 930 sph

Port Renfrew - 930 sph

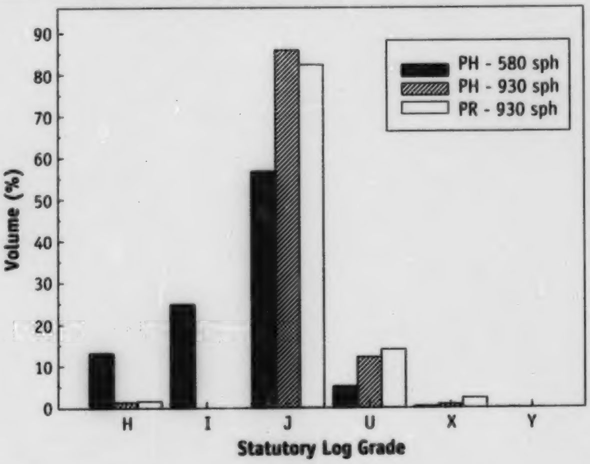
are shown in descending order by value. Also included in the table is a distribution of log grades obtained from a sample of 894 old-growth western hemlock logs graded when the present grade rules came into use (Middleton and Munro, 1985). Note that utility grade "U" was added later. Figure 2-21 provides a graphic comparison of the log volume distributions by grade for the three samples. The majority of logs generated from the three samples in this study were "J" grade, which is a good quality, small diameter sawlog (8 to 18 cm small-end radius). J grade logs 8 to 13 cm in radius permit knots up to 4 cm in diameter, those 14 to 18 cm in radius permit knots up to 6 cm in diameter.

Greater proportions of U grade logs were obtained from the two 930 sph stands compared to PH580. U grade permits logs as small as 5 cm in small-end radius, and for the same sized logs, allows knots which are 2 cm larger than those permitted in J grade. Higher proportions of U grade are

Table 2-9 *Percent Distribution of Scaled Log Volume by Log Grade*

Log Grade	PH580	PH930	PR930	Old Growth
	Percent (%)			
D	-	-	-	6.6
H	13.1	1.3	1.6	29.7
I	24.8	-		34.3
J	56.7	85.8	82.3	7.2
U	5.1	12.1	13.9	n/a
X	0.3	0.8	2.3	18.1
Y	0.1	0.1	-	4.1
Total	100.0	100.0	100.0	100.0
Log Volume (m^3)	213.24	81.90	74.49	

Figure 2-21
Stand Comparison of Log Volume Distributions by Grade



consistent with the smaller sized trees at PH930 and PR930. Small percentages of log volumes fell into a lower quality utility (X) or chipper (Y) grade.

Logs graded H or I comprised nearly 38 percent of the total log volume produced from the PH580 tree sample. These log grades require a minimum small-end log radius of 19 cm. H grade logs have a growth rate restriction of no fewer than 5 annual rings in each 2 cm of log diameter (ring width ≤4 mm), and an overall knot size restriction of 4 cm diameter. Well-spaced knots up to 5 cm in diameter are permitted in the upper 50 percent of an H grade log. I grade logs have no growth rate restriction, and depending on log size, allow larger knots. (Up to 10 cm diameter in logs ≥38 cm radius, for example.)

Taken at face value, the comparative log grade yields suggest that the PH580 tree sample was the most valuable. However, this assumes that the faster growth rate responsible for the availability of large logs had no negative implications for product attributes. Other studies have shown rapid growth rate to be associated with significant losses in structural attributes due to lower average wood density and larger average knot size. Note that the few large logs that were obtained from the two more dense stands met H Grade requirements, whereas some two-thirds of the large logs from PH580 were I Grade.

It was considered informative to compare these second-growth log grade distributions with what might be expected from old growth. As shown in Table 9, approximately 70 percent of the old growth was I Grade or higher, compared to 38 percent obtained from the largest trees (PH580) in the present study. Moreover, because stratified sampling was used in this study the larger diameter trees and logs were over-represented in relation to distribution in the stands.

Lumber Recovery

Table 2-10 shows the log top diameter distribution of the sawlogs that were converted to lumber from each tree sample. Table 2-11 compares rough green lumber recovery and dressed dry recovery by log top diameter class. Recovery

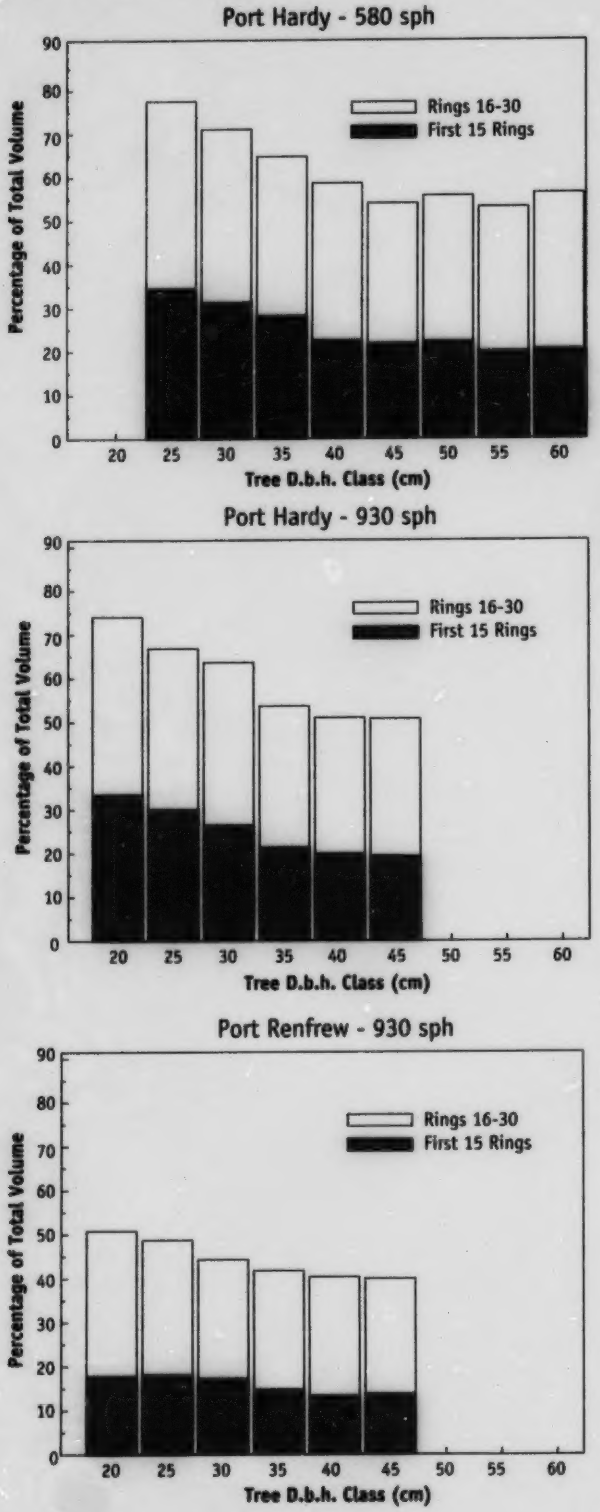
Table 2-10 *Stand and Log Diameter Distribution of Sawlogs Converted to Lumber*

Log Top Diameter Class (cm)	Stand			Total
	PH580	PH930	PR930	
20.0 - 24.9	1	-	1	2
25.0 - 29.9	90	63	62	215
30.0 - 34.9	87	47	44	178
35.0 - 39.9	74	25	17	116
40.0 - 44.9	50	3	1	54
45.0 - 49.9	34	-	-	34
50.0 - 54.9	15	-	-	15
55.0 - 59.9	1	-	-	1
Total	352	138	125	615

Table 2-11 *Percent Lumber Recovery by Stand and Log Top Diameter Class*

Log Top Diameter Class (cm)	Stand							
	PH580		PH930		PR930		Combined	
	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)
20.0 - 24.9	62.0	50.2	-	-	51.0	38.9	55.3	43.3
25.0 - 29.9	58.3	43.8	58.4	44.8	59.7	46.4	58.7	44.8
30.0 - 34.9	63.3	48.3	62.7	47.9	65.8	51.2	63.7	48.9
35.0 - 39.9	65.3	50.9	65.0	50.4	67.8	53.1	65.6	51.1
40.0 - 44.9	67.6	53.0	68.5	54.1	61.2	48.6	67.5	53.0
45.0 - 49.9	68.4	54.0	-	-	-	-	68.4	54.0
50.0 - 54.9	71.2	57.0	-	-	-	-	71.2	57.0
55.0 - 59.9	66.0	51.0	-	-	-	-	66.0	51.0
Combined	**65.2**	**50.7**	**62.0**	**47.6**	**63.5**	**49.5**	**64.3**	**49.9**

Figure 2-20
Proportions of Juvenile Wood



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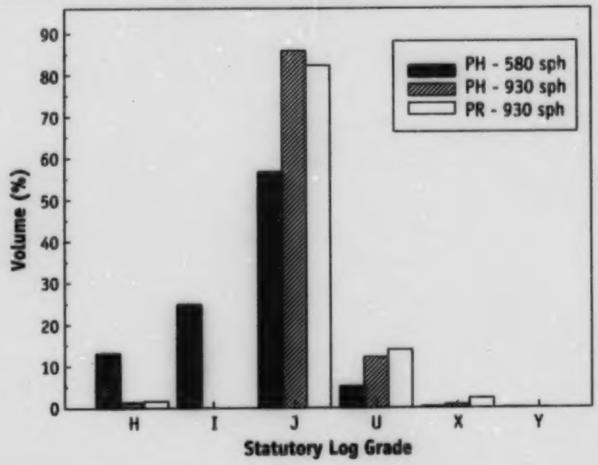

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45.0 - 49.9	34	-	-	34
50.0 - 54.9	15	-	-	15
55.0 - 59.9	1	-	-	1
Total	352	138	125	615

Table 2-11 *Percent Lumber Recovery by Stand and Log Top Diameter Class*

Log Top Diameter Class (cm)	Stand							
	PH580		PH930		PR930		Combined	
	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)	Rough-Green Recovery (%)	Dressed-Dry Recovery (%)
20.0 - 24.9	62.0	50.2	-	-	51.0	38.9	55.3	43.3
25.0 - 29.9	58.3	43.8	58.4	44.8	59.7	46.4	58.7	44.8
30.0 - 34.9	63.3	48.3	62.7	47.9	65.8	51.2	63.7	48.9
35.0 - 39.9	65.3	50.9	65.0	50.4	67.8	53.1	65.6	51.1
40.0 - 44.9	67.6	53.0	68.5	54.1	61.2	48.6	67.5	53.0
45.0 - 49.9	68.4	54.0	-	-	-	-	68.4	54.0
50.0 - 54.9	71.2	57.0	-	-	-	-	71.2	57.0
55.0 - 59.9	66.0	51.0	-	-	-	-	66.0	51.0
Combined	**65.2**	**50.7**	**62.0**	**47.6**	**63.5**	**49.5**	**64.3**	**49.9**

was calculated as lumber volume divided by log volume with lumber volumes calculated from the full size of each piece. The rough green lumber recovery is illustrated in Figure 2-22, and the dressed dry recovery is illustrated in Figure 2-23.

Dressed dry lumber recovery was consistently 14 to 15 percentage points lower than rough green recovery for all three log samples. Because it was necessary to plane numerous random width side cuts down to a manageable number of sizes, the green recovery numbers provide the best estimates of relative lumber recovery potential. As noted earlier, the mill did not have modern optimization equipment.

Over the 25.0 to 39.9 cm range in log top diameter in which there were numerous logs from all three samples, lumber recovery obtained from the PR930 stand exceeded that from the other two stands. When tested over three common top diameter classes, the difference was significant for PR930 compared to PH930, but not for PR930 compared to PH580.

Figure 2-22
Rough Green Lumber Recovery

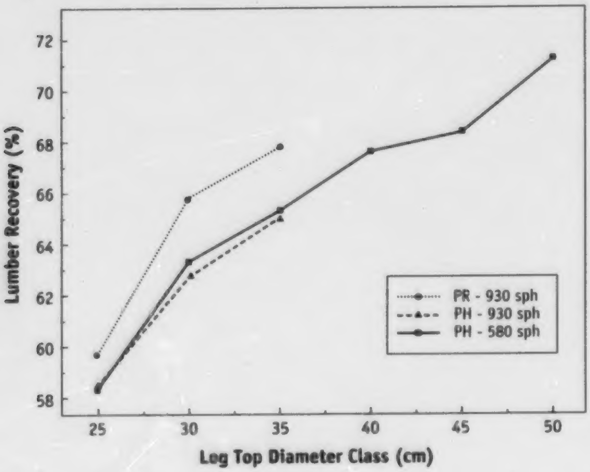
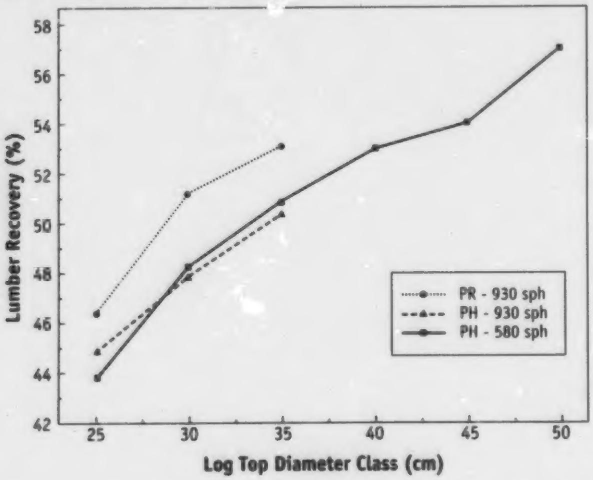


Figure 2-23
Dressed Dry Lumber Recovery



In a previous study of lodgepole pine (Middleton et al. 1995), higher lumber recovery for trees from relatively high stand density was associated with lower taper. A comparison of sawlog taper by stand in this study revealed that mean sawlog taper was highest (0.67 cm/m) for the PH580 sample as expected, but the taper in trees from PR930 (0.61 cm/m) was not significantly different. Taper in the PH930 sample (0.58 cm/m) was not different from PR930, but was significantly lower than that of PH580. In spite of this difference, lumber recovery from the two Port Hardy sawlog samples was nearly identical over the common range of sawlog diameter. Differences in taper were not responsible for the higher recovery at PR930. A review of tree and log quality information provided no other plausible explanation.

Table 2-12 shows total dressed dry lumber volume distributed by dimension. The total volume was 126.12 m^3 of which 87.25 m^3 was squares, 21.15 m^3 was 36 mm, and 17.73 m^3 was 45 mm. Table 2-13 provides a percentage breakdown by lumber size. Squares, the majority of which were 105x105 mm, were about 70 percent of the lumber. The numerical distribution of lumber by size for each stand is provided in Table 2-14.

Table 2-12 *Distribution of Total Lumber Volume by Dimension*

Size (mm)	Stand			Total
	PH580	PH930	PR930	
	Volume (m^3)			
105 x 105	55.32	13.53	12.08	80.93
90 x 90	3.39	1.84	1.09	6.32
36 x 60	0.88	0.45	0.37	1.71
36 x 90	1.27	0.58	0.55	2.40
36 x 105	1.83	0.67	0.59	3.08
36 x 140	5.74	1.80	2.02	9.56
36 x 190	2.79	0.42	0.30	3.52
36 x 240+	0.78	0.03	0.07	0.88
45 x 60	0.63	0.31	0.17	1.11
45 x 90	1.60	0.42	0.28	2.30
45 x 105	5.92	2.12	2.01	10.05
45 x 140	1.06	0.26	0.18	1.49
45 x 190	1.13	0.46	0.38	1.97
45 x 240+	0.81	-	-	0.81
Total	83.14	22.89	20.09	126.12

Table 2-13 *Distribution of Total Lumber Volume by Dimension*

Size (mm)	Stand			Total
	PH580	PH930	PR930	
	Percent (%)			
105 x 105	66.5	59.1	60.1	64.2
90 x 90	4.1	8.0	5.4	5.0
36 x 60	1.1	2.0	1.9	1.4
36 x 90	1.5	2.5	2.8	1.9
36 x 105	2.2	2.9	2.9	2.4
36 x 140	6.9	7.9	10.0	7.6
36 x 190	3.4	1.8	1.5	2.8
36 x 240+	0.9	0.2	0.4	0.7
45 x 60	0.8	1.3	0.9	0.9
45 x 90	1.9	1.8	1.4	1.8
45 x 105	7.1	9.3	10.0	8.0
45 x 140	1.3	1.1	0.9	1.2
45 x 190	1.4	2.0	1.9	1.6
45 x 240+	1.0	-	-	0.6
Total	100.0	100.0	100.0	100.0

Table 2-14 *Distribution of Lumber Piece Count by Dimension*

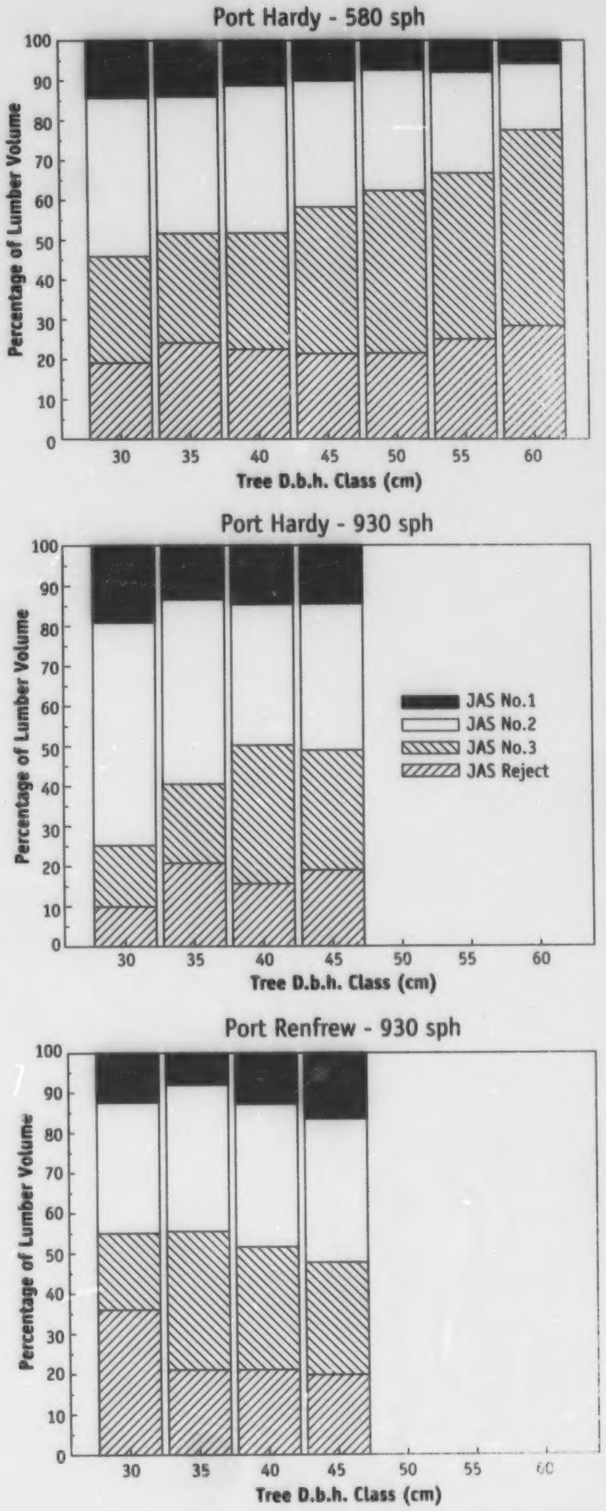
Size (mm)	Stand			Total
	PH580	PH930	PR930	
105 x 105	1,293	311	280	1,884
90 x 90	109	58	37	204
36 x 60	136	67	55	258
36 x 90	125	56	53	234
36 x 105	158	55	49	262
36 x 140	317	98	109	524
36 x 190	118	18	13	149
36 x 240+	24	1	2	27
45 x 60	78	34	20	132
45 x 90	109	29	19	157
45 x 105	341	121	115	577
45 x 140	50	11	8	69
45 x 190	38	14	13	65
45 x 240+	19	-	-	19
Total	2,915	873	773	4,561

Visually Determined Lumber Grades

JAS Grade Yields

Distributions of lumber volumes by JAS grades for each of the three tree samples are shown in Table 2-15 and illustrated in Figure 2-24.

Figure 2-24
Distribution of Lumber by JAS Grade



was calculated as lumber volume divided by log volume with lumber volumes calculated from the full size of each piece. The rough green lumber recovery is illustrated in Figure 2-22, and the dressed dry recovery is illustrated in Figure 2-23.

Dressed dry lumber recovery was consistently 14 to 15 percentage points lower than rough green recovery for all three log samples. Because it was necessary to plane numerous random width side cuts down to a manageable number of sizes, the green recovery numbers provide the best estimates of relative lumber recovery potential. As noted earlier, the mill did not have modern optimization equipment.

Over the 25.0 to 39.9 cm range in log top diameter in which there were numerous logs from all three samples, lumber recovery obtained from the PR930 stand exceeded that from the other two stands. When tested over three common top diameter classes, the difference was significant for PR930 compared to PH930, but not for PR930 compared to PH580.

Figure 2-22

Rough Green Lumber Recovery

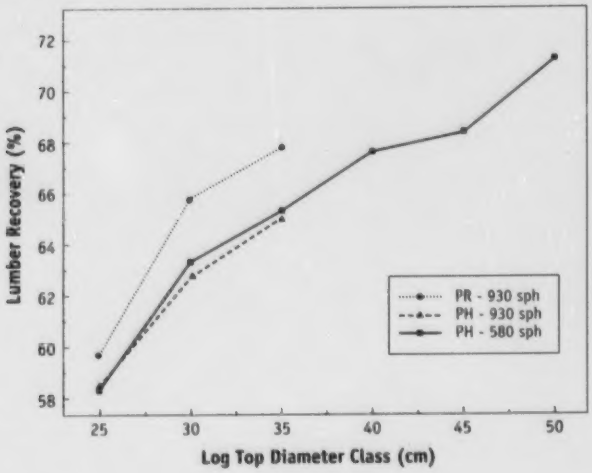
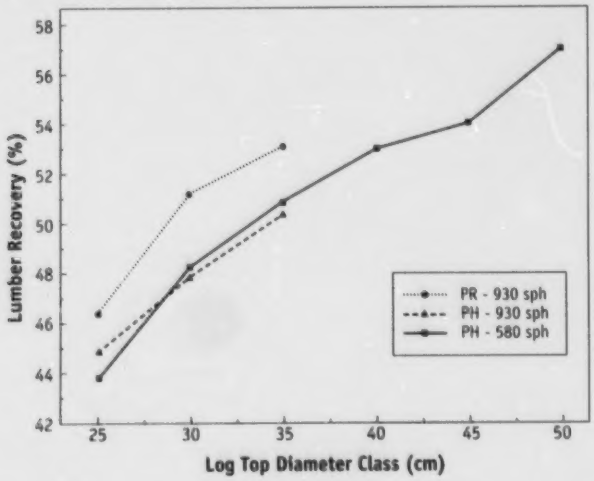


Figure 2-23

Dressed Dry Lumber Recovery



In a previous study of lodgepole pine (Middleton et al. 1995), higher lumber recovery for trees from relatively high stand density was associated with lower taper. A comparison of sawlog taper by stand in this study revealed that mean sawlog taper was highest (0.67 cm/m) for the PH580 sample as expected, but the taper in trees from PR930 (0.61 cm/m) was not significantly different. Taper in the PH930 sample (0.58 cm/m) was not different from PR930, but was significantly lower than that of PH580. In spite of this difference, lumber recovery from the two Port Hardy sawlog samples was nearly identical over the common range of sawlog diameter. Differences in taper were not responsible for the higher recovery at PR930. A review of tree and log quality information provided no other plausible explanation.

Table 2-12 shows total dressed dry lumber volume distributed by dimension. The total volume was 126.12 m^3 of which 87.25 m^3 was squares, 21.15 m^3 was 36 mm, and 17.73 m^3 was 45 mm. Table 2-13 provides a percentage breakdown by lumber size. Squares, the majority of which were 105x105 mm, were about 70 percent of the lumber. The numerical distribution of lumber by size for each stand is provided in Table 2-14.

Table 2-12 *Distribution of Total Lumber Volume by Dimension*

Size (mm)	Stand			Total
	PH580	PH930	PR930	
	Volume (m^3)			
105 x 105	55.32	13.53	12.08	80.93
90 x 90	3.39	1.84	1.09	6.32
36 x 60	0.88	0.45	0.37	1.71
36 x 90	1.27	0.58	0.55	2.40
36 x 105	1.83	0.67	0.59	3.08
36 x 140	5.74	1.80	2.02	9.56
36 x 190	2.79	0.42	0.30	3.52
36 x 240+	0.78	0.03	0.07	0.88
45 x 60	0.63	0.31	0.17	1.11
45 x 90	1.60	0.42	0.28	2.30
45 x 105	5.92	2.12	2.01	10.05
45 x 140	1.06	0.26	0.18	1.49
45 x 190	1.13	0.46	0.38	1.97
45 x 240+	0.81	-	-	0.81
Total	83.14	22.89	20.09	126.12

Table 2-13 *Distribution of Total Lumber Volume by Dimension*

Size (mm)	Stand			Total
	PH580	PH930	PR930	
	Percent (%)			
105 x 105	66.5	59.1	60.1	64.2
90 x 90	4.1	8.0	5.4	5.0
36 x 60	1.1	2.0	1.9	1.4
36 x 90	1.5	2.5	2.8	1.9
36 x 105	2.2	2.9	2.9	2.4
36 x 140	6.9	7.9	10.0	7.6
36 x 190	3.4	1.8	1.5	2.8
36 x 240+	0.9	0.2	0.4	0.7
45 x 60	0.8	1.3	0.9	0.9
45 x 90	1.9	1.8	1.4	1.8
45 x 105	7.1	9.3	10.0	8.0
45 x 140	1.3	1.1	0.9	1.2
45 x 190	1.4	2.0	1.9	1.6
45 x 240+	1.0	-	-	0.6
Total	100.0	100.0	100.0	100.0

Table 2-14 *Distribution of Lumber Piece Count by Dimension*

Size (mm)	Stand			Total
	PH580	PH930	PR930	
105 x 105	1,293	311	280	1,884
90 x 90	109	58	37	204
36 x 60	136	67	55	258
36 x 90	125	56	53	234
36 x 105	158	55	49	262
36 x 140	317	98	109	524
36 x 190	118	18	13	149
36 x 240+	24	1	2	27
45 x 60	78	34	20	132
45 x 90	109	29	19	157
45 x 105	341	121	115	577
45 x 140	50	11	8	69
45 x 190	38	14	13	65
45 x 240+	19	-	-	19
Total	2,915	873	773	4,561

Visually Determined Lumber Grades

JAS Grade Yields

Distributions of lumber volumes by JAS grades for each of the three tree samples are shown in Table 2-15 and illustrated in Figure 2-24.

Figure 2-24
Distribution of Lumber by JAS Grade

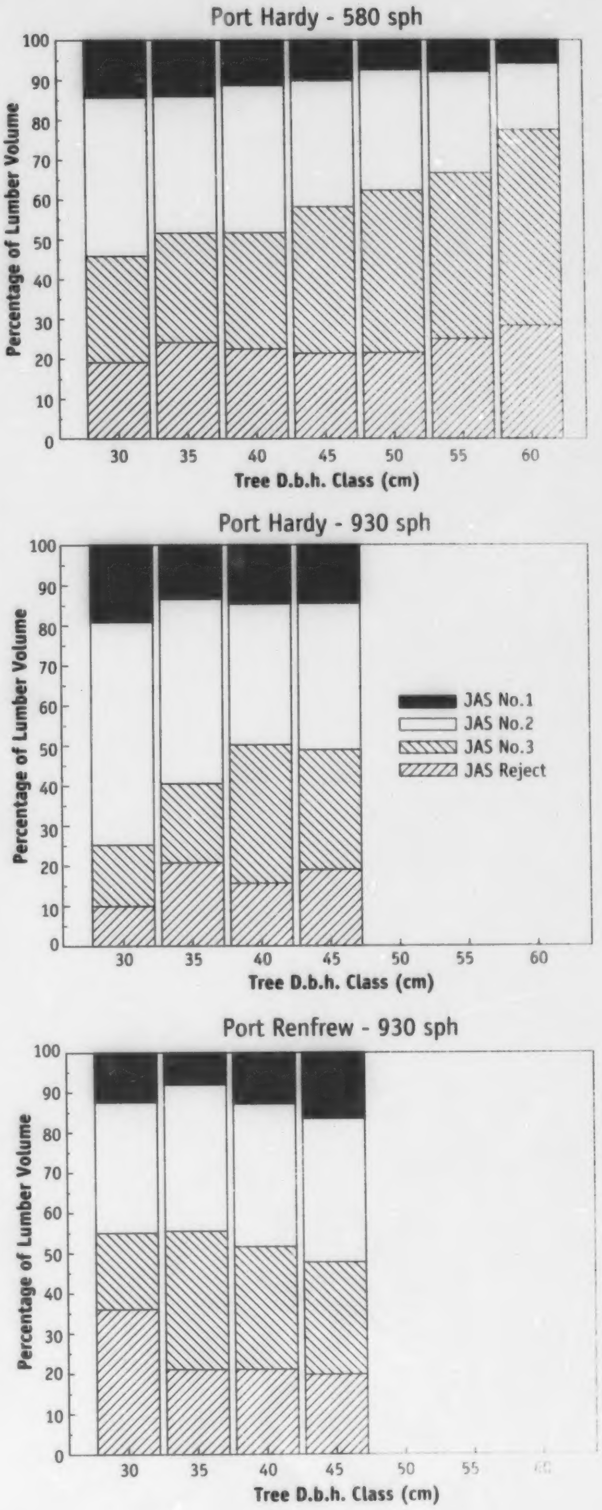


Table 2-15 *Percentage Distribution of Total Lumber Volume by JAS Grade*

Stand	Tree D.b.h. Class (cm)	JAS No. 1	JAS No. 2	JAS No. 3	JAS Reject	Combined
		Percent (%)				
PH580	30	14.3	39.9	26.7	19.1	100.0
	35	14.0	34.4	27.5	24.1	100.0
	40	11.2	37.1	29.2	22.5	100.0
	45	10.1	31.1	36.8	21.4	100.0
	50	7.3	30.4	40.8	21.5	100.0
	55	7.8	25.5	41.7	25.0	100.0
	60	5.7	16.8	49.2	28.3	100.0
	Combined	8.1	26.6	40.9	24.4	100.0
PH930	30	19.2	55.7	15.3	9.9	100.0
	35	13.4	46.1	19.7	20.8	100.0
	40	14.6	35.2	34.6	15.6	100.0
	45	14.5	36.6	29.9	19.9	100.0
	Combined	14.6	38.9	28.8	17.7	100.0
PR930	30	12.4	32.6	19.0	36.0	100.0
	35	7.9	36.7	34.4	21.1	100.0
	40	12.8	35.6	30.5	21.1	100.0
	45	16.5	35.8	27.9	19.8	100.0
	Combined	13.7	35.7	29.4	21.2	100.0
Combined		10.2	30.3	36.8	22.7	100.0

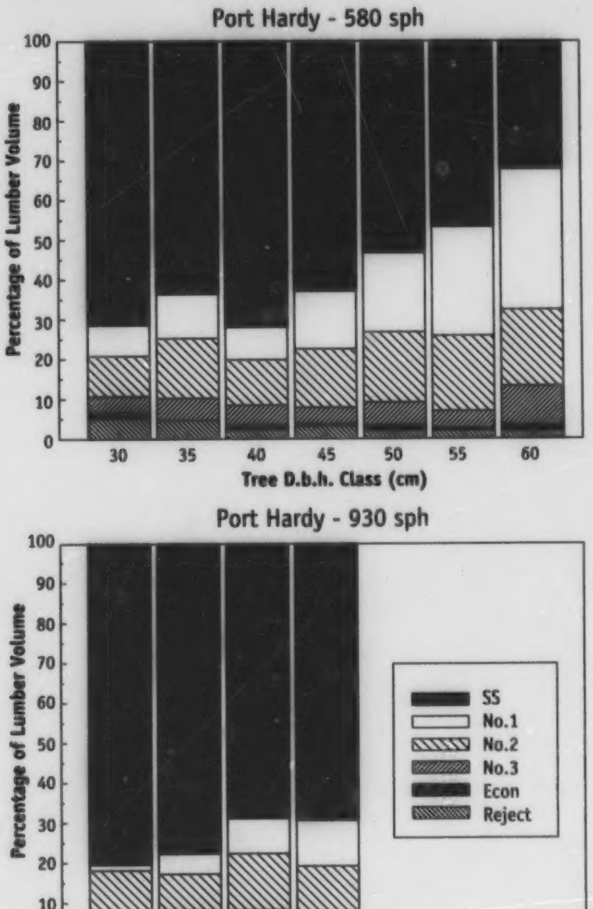
Table 2-16 *Percent Lumber Volume Distribution by Reason for JAS Grade Reduction*

Defect	Stand PH580	Stand PH930	Stand PR 930	Combined
None	8.1	14.6	13.7	10.2
Wane	6.5	9.1	8.4	7.3
Knots	72.8	57.5	60.0	68.0
Unsound wood	0.1	0.4	0.3	0.1
White specks	0.0	0.1	0.2	0.1
Honeycomb	0.1	-	-	0.0
Heart shake	0.7	0.1	0.2	0.5
Ring shake	0.2	-	0.1	0.1
Pin holes	-	0.4	-	0.1
Pockets	0.1	-	-	0.1
Compression wood	0.1	0.2	-	0.1
Slope of Grain	0.8	2.0	4.0	1.5
Skips	4.9	9.4	7.6	6.2
Bruise/machine damage	1.9	1.6	2.4	1.9
Warp	0.3	0.2	0.3	0.3
Falling breaks	0.9	1.7	0.3	1.0
Scant/undersize	0.2	0.5	0.4	0.3
Grain distortion	0.1	0.4	-	0.1
Too short	2.1	1.8	2.3	2.1
Total	100.0	100.0	100.0	100.0

Table 2-17 *Percentage Distribution of Total Lumber Volume by NLGA Grade*

Stand	Tree D.b.h. Class (cm)	NLGA SS	NLGA No. 1	NLGA No. 2	NLGA No. 3	NLGA Econ	NLGA Reject	Combined
		Percent (%)						
PH580	30	71.4	7.8	10.1	4.2	1.3	5.2	100.0
	35	63.5	11.2	15.0	5.5	-	4.7	100.0
	40	71.9	8.3	11.4	5.1	0.8	2.5	100.0
	45	62.9	14.6	14.7	4.2	0.3	3.3	100.0
	50	53.2	20.0	17.6	5.9	1.1	2.1	100.0
	55	46.7	27.5	18.9	4.3	0.4	2.2	100.0
	60	32.2	35.5	19.1	9.9	1.4	1.9	100.0
	Combined	49.6	23.7	17.1	6.4	0.8	2.5	100.0
PH930	30	80.5	1.5	16.4	1.7	-	-	100.0
	35	78.0	5.1	9.3	1.8	1.6	4.3	100.0
	40	68.8	8.9	14.2	1.8	1.6	4.3	100.0
	45	69.2	11.5	12.7	2.5	0.3	3.9	100.0
	Combined	71.3	8.9	12.8	3.6	0.6	2.8	100.0
PR 930	30	73.4	5.7	14.8	5.2	-	0.9	100.0
	35	53.0	6.2	18.4	19.9	0.5	1.8	100.0
	40	64.4	10.5	14.7	8.0	-	2.4	100.0
	45	67.6	12.9	14.0	4.8	-	0.6	100.0
	Combined	64.5	10.7	15.0	8.4	0.1	1.4	100.0
Combined		55.9	18.9	16.0	6.2	0.7	2.3	100.0

Figure 2-25
Distribution of Lumber by NLGA Grade



PH930 had the highest proportions of Grades No. 1 and 2 and lowest proportion of Reject. A significant drop in the proportion of Grade No. 1 lumber from PH580 occurred as d.b.h. class increased. There was also a decline in the proportion of Grade No. 2, and a corresponding increase in Grade No. 3. Proportions of Reject increased from 19 to 28 percent as size class increased from 30 to 60 cm. There is much less evidence of a similar trend in the PR930 stand.

Reasons for JAS grade reductions are summarized in Table 2-16. Knots were the most significant grade-determining factor. Wane and manufacturing defects (skip, machine damage, scant/undersize) were next most responsible for grade loss. (Unsound wood at lumber ends, which was identified as being the result of the prolonged log storage, was recorded to be considered or excluded from other tests, but was not included as a reason for degrade here.)

NLGA Grade Yields

NLGA grade yields are provided in Table 2-17 and illustrated in Figure 2-25. Similar to the results for JAS grades, the proportion of Select Structural Lumber generally declined as tree size increased. For the PH580 stand it dropped from 71 percent in the 30 cm tree d.b.h. class to 32 percent in the 60 cm class. The PH930 sample produced the highest proportion of Select Structural lumber. The lowest proportion was obtained from the PH580 sample. Unlike the grade outturn for JAS rules, there was very little reject lumber.

Reasons for NLGA grade reductions are shown in Table 2-18. Lumber for which there was no grade reduction was 71 and 65 percent of the volume from PH930 and PR930 respectively. On the other hand, only 50 percent of the lumber from PH580 escaped a grade reduction. The reason is evident in the reductions for knots. So much of the lumber from all three samples was down-graded for knots under JAS rules, that these results for structural lumber provide the best indication of how the relatively low stand density at PH580 affects product potential. The highest visual grade outturn was obtained from PH930, consistent with the results under JAS rules.

Note that the smallest d.b.h. class trees were not converted to lumber. These 20 and 25 cm class trees could be expected to have grade yields similar to, or better than, those of the 30 cm classes.

There was very little grade reduction for drying defects (warp, splits) under this rule or previously under the JAS rule.

Knots as Grade Limiting Factors

JAS Grade Yields Determined by Knots Only

Differences in stand density are known to influence knot size, but the effects on product grade have generally not been quantified. Percentage grade distributions obtained from grading each piece of lumber under JAS rules for knot

M121

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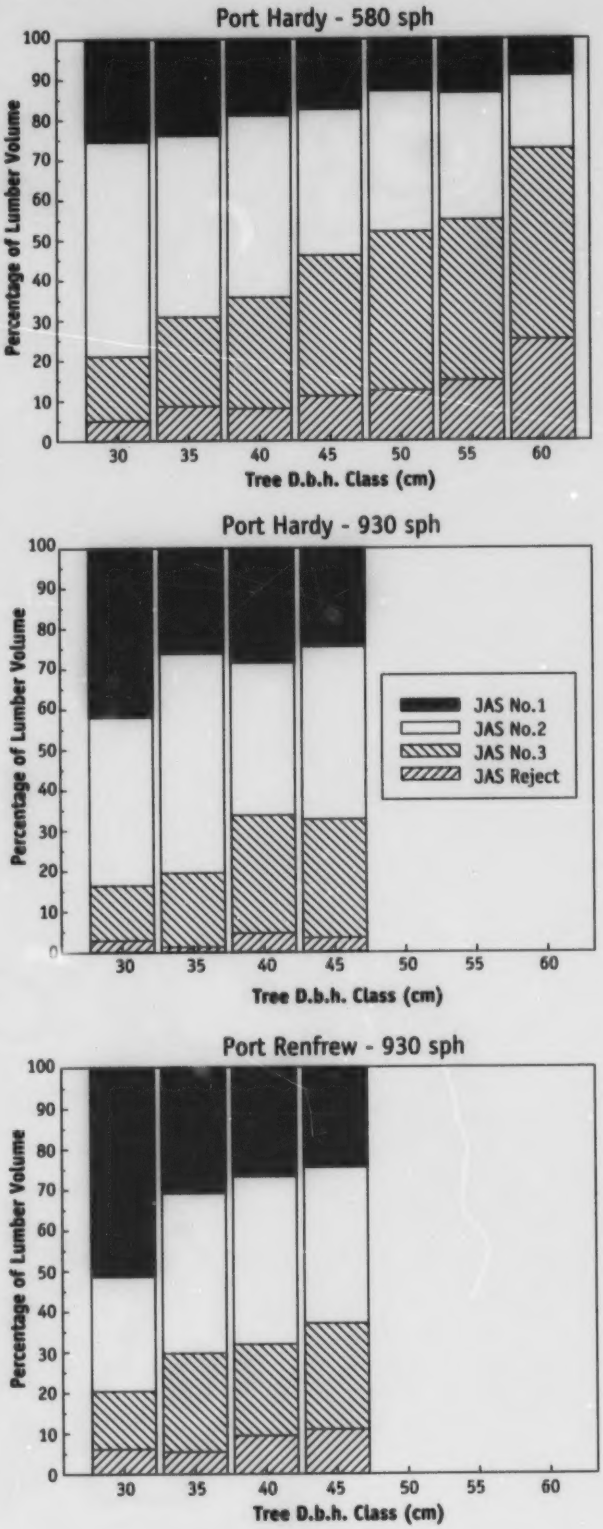
Table 2-18 *Percent Lumber Volume Distribution by Reason for NLGA Grade Reduction*

Defect	Stand			Combined
	PH580	PH930	PR930	
None	49.6	71.3	64.5	55.9
Wane	6.8	5.1	7.3	6.5
Knots	33.8	11.3	13.6	26.6
Unsound wood	0.1	0.2	0.1	0.1
White specks	0.2	0.2	0.2	0.2
Honeycomb	0.1	-	-	0.0
Heart stain	0.0	-	-	0.0
Heart shake	1.9	1.1	0.6	1.5
Ring shake	0.2	-	0.1	0.1
Compression wood	-	0.2	-	0.0
Slope of Grain	1.5	3.3	6.6	2.6
Skips	3.3	4.1	5.1	3.8
Bruise/machine damage	0.6	0.4	0.7	0.6
Splits	-	-	0.1	0.0
Warp	0.3	0.4	0.4	0.3
Falling breaks	0.9	1.7	0.3	0.9
Scant/undersize	0.3	0.2	0.5	0.3
Grain distortion	0.3	0.6	-	0.3
Total	100.0	100.0	100.0	100.0

Table 2-19 *Percentage Distribution of Lumber Volume by JAS Grade Determined for Knots Only*

Stand	Tree D.b.h. Class (cm)	JAS Knot Grade				Combined
		No. 1	No. 2	No. 3	Reject	
		Percent (%)				
PH580	30	25.5	53.5	16.0	5.0	100.0
	35	23.9	45.3	22.2	8.6	100.0
	40	19.0	45.4	27.7	8.0	100.0
	45	17.3	36.5	35.0	11.1	100.0
	50	12.9	35.1	39.6	12.4	100.0
	55	13.4	31.7	40.0	14.9	100.0
	60	9.1	18.3	47.5	25.1	100.0
	Combined	13.8	31.5	39.0	15.7	100.0
PH930	30	41.9	41.7	13.6	2.8	100.0
	35	26.2	54.3	18.3	1.2	100.0
	40	28.4	37.8	29.1	4.6	100.0
	45	24.5	42.8	29.3	3.4	100.0
	Combined	27.1	43.2	26.4	3.4	100.0
PR930	30	51.4	28.3	14.3	6.1	100.0
	35	30.7	39.5	24.3	5.4	100.0
	40	26.7	41.4	22.5	9.4	100.0
	45	24.5	38.5	26.1	10.9	100.0
	Combined	27.6	39.1	24.1	9.3	100.0
Combined		18.4	34.8	34.3	12.5	100.0

Figure 2-26
Distribution of JAS Grade Determined by Knots Only



size only are shown in Table 2-19 and illustrated in Figure 2-26. The proportion of JAS Grade No. 1 generally increased, and the proportion of reject declined because other grade limiting factors were ignored, but there is a persistent reduction in proportions of JAS No. 1 and JAS No. 2 grades as tree size increases. The trend is nearly identical in all three of the tree samples and the reductions continue to increase over the larger d.b.h. classes obtained from PH580. This indicates that reducing stand density and growing larger trees in rotations of 90 years or less will reduce proportions of premium JAS lumber grades. Trends toward increased knot size in faster grown trees are consistent with expectations.

This effect of knot size and frequency on grade yield is likely underestimated here because small logs were not converted to lumber. In the larger d.b.h. classes these small logs would have come from the crown and knots would be the major grade-limiting defect. More wane might be expected also.

NLGA Grade Yields Determined by Knots Only

A similar distribution of NLGA lumber grade percentages determined for knots only is shown in Table 2-20 and illustrated in Figure 2-27. For trees in the 30 to 45 cm d.b.h. classes, knots were not a serious grade-limiting defect. Select Structural lumber represented from 76 to 97 percent of the grade yields. Proportions of Select Structural began to decline in the 45 cm class and in the PH580 sample were reduced to only 41 percent in the 60 cm class. Rapid growth to achieve large diameter trees in rotations of 90 years or less will result in lower proportions of Select Structural lumber, but for the most part the grade is reduced no lower than to No.1.

Relative Effect of Knot Location on JAS and NLGA Lumber Grade Yields

Lumber grades are often determined by knot location. The overall recovery of JAS No.1 (10.2%) was much lower than the overall recovery of Select Structural (55.9%). Similarly, overall JAS Reject (22.7%) was much higher than overall NLGA Economy plus Reject (3.0%).

Table 2-21 shows how knot type and position contributed to reductions for knots in JAS grades determined for knots only. Edge knots were most responsible for grade reductions. Table 2-22 provides the same information for NLGA grades. Edge knots remain most responsible for grade loss, but centreline knots are also important. Edge knots have more restrictive size limits for both grade rules, but NLGA allows a 19% larger edge knot (19 mm) in Select Structural than than JAS allows in No. 1 (16 mm). NLGA also allows a 19% larger edge knot (44 mm) in its lowest grade than JAS (37 mm) which results in a higher percentage of Reject under JAS rules.

Table 2-20 *Percentage Distribution of Lumber Volume by NLGA Grades Determined for Knots Only*

Stand	Tree D.b.h. Class (cm)	NLGA Knot Grade						Combined
		SS	No. 1	No. 2	No. 3	Econ	Reject	
		Percent (%)						
PH580	30	93.0	5.9	-	1.1	-	-	100.0
	35	85.8	10.9	1.8	1.5	-	-	100.0
	40	87.2	10.4	1.4	0.6	0.3	-	100.0
	45	76.4	17.7	3.9	1.8	0.2	-	100.0
	50	64.2	23.3	9.1	2.7	0.8	-	100.0
	55	58.2	32.5	6.4	2.3	0.7	0.0	100.0
	60	40.6	38.1	14.4	5.4	1.2	0.4	100.0
	Combined	61.4	26.7	8.1	3.0	0.7	0.1	100.0
PH930	30	96.8	1.5	1.2	0.5	-	-	100.0
	35	93.2	5.4	1.0	0.5	-	-	100.0
	40	88.2	9.3	1.4	1.1	-	-	100.0
	45	81.2	14.9	2.9	0.9	0.1	-	100.0
	Combined	86.5	10.6	2.0	0.9	0.0	-	100.0
PR930	30	87.9	10.6	1.6	-	-	-	100.0
	35	87.6	10.7	1.1	0.6	-	-	100.0
	40	85.4	11.5	1.6	1.4	0.1	-	100.0
	45	81.0	13.8	3.2	1.7	0.1	-	100.0
	Combined	83.8	12.4	2.3	1.4	0.1	0.1	100.0
Combined		69.5	21.5	6.1	2.3	0.5	0.1	100.0

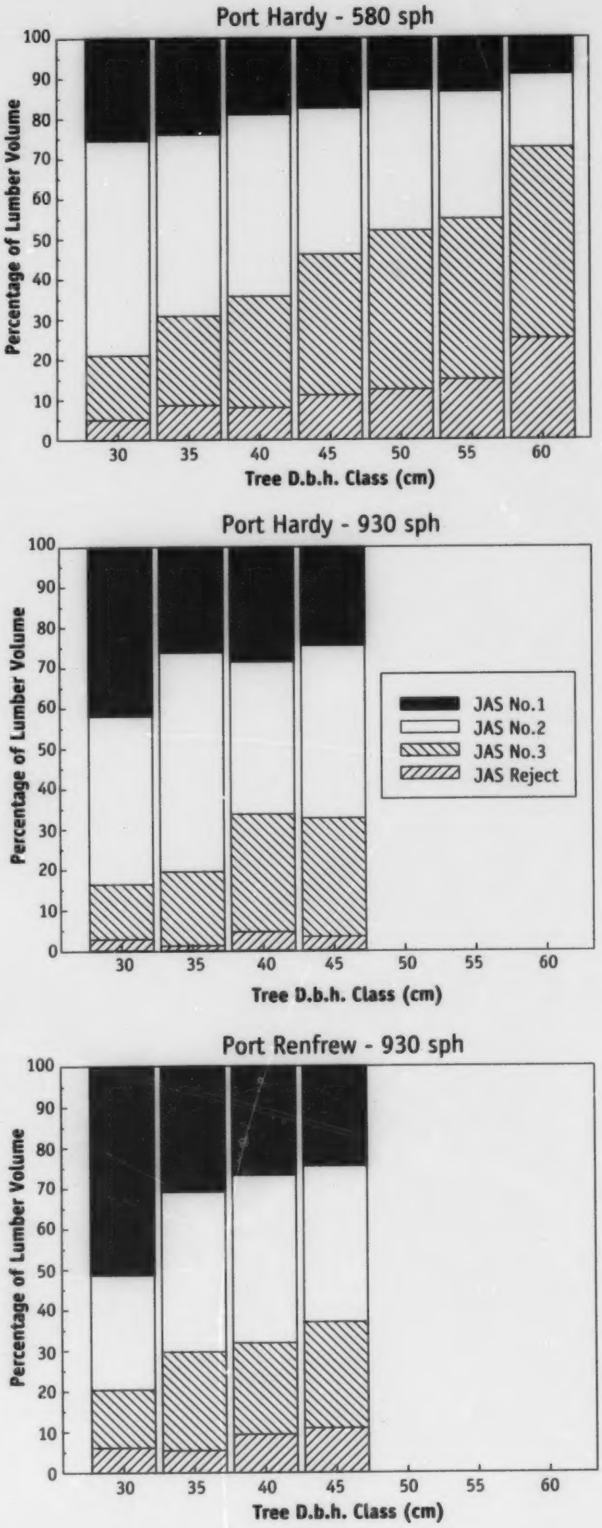
Table 2-18 *Percent Lumber Volume Distribution by Reason for NLGA Grade Reduction*

Defect	Stand			Combined
	PH580	PH930	PR930	
None	49.6	71.3	64.5	55.9
Wane	6.8	5.1	7.3	6.5
Knots	33.8	11.3	13.6	26.6
Unsound wood	0.1	0.2	0.1	0.1
White specks	0.2	0.2	0.2	0.2
Honeycomb	0.1	-	-	0.0
Heart stain	0.0	-	-	0.0
Heart shake	1.9	1.1	0.6	1.5
Ring shake	0.2	-	0.1	0.1
Compression wood	-	0.2	-	0.0
Slope of Grain	1.5	3.3	6.6	2.6
Skips	3.3	4.1	5.1	3.8
Bruise/machine damage	0.6	0.4	0.7	0.6
Splits	-	-	0.1	0.0
Warp	0.3	0.4	0.4	0.3
Falling breaks	0.9	1.7	0.3	0.9
Scant/undersize	0.3	0.2	0.5	0.3
Grain distortion	0.3	0.6	-	0.3
Total	100.0	100.0	100.0	100.0

Table 2-19 *Percentage Distribution of Lumber Volume by JAS Grade Determined for Knots Only*

Stand	Tree D.b.h. Class (cm)	JAS Knot Grade				Combined
		No. 1	No. 2	No. 3	Reject	
		Percent (%)				
PH580	30	25.5	53.5	16.0	5.0	100.0
	35	23.9	45.3	22.2	8.6	100.0
	40	19.0	45.4	27.7	8.0	100.0
	45	17.3	36.5	35.0	11.1	100.0
	50	12.9	35.1	39.6	12.4	100.0
	55	13.4	31.7	40.0	14.9	100.0
	60	9.1	18.3	47.5	25.1	100.0
	Combined	13.8	31.5	39.0	15.7	100.0
PH930	30	41.9	41.7	13.6	2.8	100.0
	35	26.2	54.3	18.3	1.2	100.0
	40	28.4	37.8	29.1	4.6	100.0
	45	24.5	42.8	29.3	3.4	100.0
	Combined	27.1	43.2	26.4	3.4	100.0
PR930	30	51.4	28.3	14.3	6.1	100.0
	35	30.7	39.5	24.3	5.4	100.0
	40	26.7	41.4	22.5	9.4	100.0
	45	24.5	38.5	26.1	10.9	100.0
	Combined	27.6	39.1	24.1	9.3	100.0
Combined		18.4	34.8	34.3	12.5	100.0

Figure 2-26
Distribution of JAS Grade Determined by Knots Only



size only are shown in Table 2-19 and illustrated in Figure 2-26. The proportion of JAS Grade No. 1 generally increased, and the proportion of reject declined because other grade limiting factors were ignored, but there is a persistent reduction in proportions of JAS No. 1 and JAS No. 2 grades as tree size increases. The trend is nearly identical in all three of the tree samples and the reductions continue to increase over the larger d.b.h. classes obtained from PH580. This indicates that reducing stand density and growing larger trees in rotations of 90 years or less will reduce proportions of premium JAS lumber grades. Trends toward increased knot size in faster grown trees are consistent with expectations.

This effect of knot size and frequency on grade yield is likely underestimated here because small logs were not converted to lumber. In the larger d.b.h. classes these small logs would have come from the crown and knots would be the major grade-limiting defect. More wane might be expected also.

NLGA Grade Yields Determined by Knots Only

A similar distribution of NLGA lumber grade percentages determined for knots only is shown in Table 2-20 and illustrated in Figure 2-27. For trees in the 30 to 45 cm d.b.h. classes, knots were not a serious grade-limiting defect. Select Structural lumber represented from 76 to 97 percent of the grade yields. Proportions of Select Structural began to decline in the 45 cm class and in the PH580 sample were reduced to only 41 percent in the 60 cm class. Rapid growth to achieve large diameter trees in rotations of 90 years or less will result in lower proportions of Select Structural lumber, but for the most part the grade is reduced no lower than to No.1.

Relative Effect of Knot Location on JAS and NLGA Lumber Grade Yields

Lumber grades are often determined by knot location. The overall recovery of JAS No.1 (10.2%) was much lower than the overall recovery of Select Structural (55.9%). Similarly, overall JAS Reject (22.7%) was much higher than overall NLGA Economy plus Reject (3.0%).

Table 2-21 shows how knot type and position contributed to reductions for knots in JAS grades determined for knots only. Edge knots were most responsible for grade reductions. Table 2-22 provides the same information for NLGA grades. Edge knots remain most responsible for grade loss, but centreline knots are also important. Edge knots have more restrictive size limits for both grade rules, but NLGA allows a 19% larger edge knot (19 mm) in Select Structural than than JAS allows in No. 1 (16 mm). NLGA also allows a 19% larger edge knot (44 mm) in its lowest grade than JAS (37 mm) which results in a higher percentage of Reject under JAS rules.

Table 2-20 *Percentage Distribution of Lumber Volume by NLGA Grades Determined for Knots Only*

Stand	Tree D.b.h. Class (cm)	NLGA Knot Grade						Combined
		SS	No. 1	No. 2	No. 3	Econ	Reject	
		Percent (%)						
PH580	30	93.0	5.9	-	1.1	-	-	100.0
	35	85.8	10.9	1.8	1.5	-	-	100.0
	40	87.2	10.4	1.4	0.6	0.3	-	100.0
	45	76.4	17.7	3.9	1.8	0.2	-	100.0
	50	64.2	23.3	9.1	2.7	0.8	-	100.0
	55	58.2	32.5	6.4	2.3	0.7	0.0	100.0
	60	40.6	38.1	14.4	5.4	1.2	0.4	100.0
	Combined	61.4	26.7	8.1	3.0	0.7	0.1	100.0
PH930	30	96.8	1.5	1.2	0.5	-	-	100.0
	35	93.2	5.4	1.0	0.5	-	-	100.0
	40	88.2	9.3	1.4	1.1	-	-	100.0
	45	81.2	14.9	2.9	0.9	0.1	-	100.0
	Combined	86.5	10.6	2.0	0.9	0.0	-	100.0
PR930	30	87.9	10.6	1.6	-	-	-	100.0
	35	87.6	10.7	1.1	0.6	-	-	100.0
	40	85.4	11.5	1.6	1.4	0.1	-	100.0
	45	81.0	13.8	3.2	1.7	0.1	-	100.0
	Combined	83.8	12.4	2.3	1.4	0.1	0.1	100.0
Combined		69.5	21.5	6.1	2.3	0.5	0.1	100.0

Figure 2-27
Distribution of NLGA Grade Determined by Knots Only

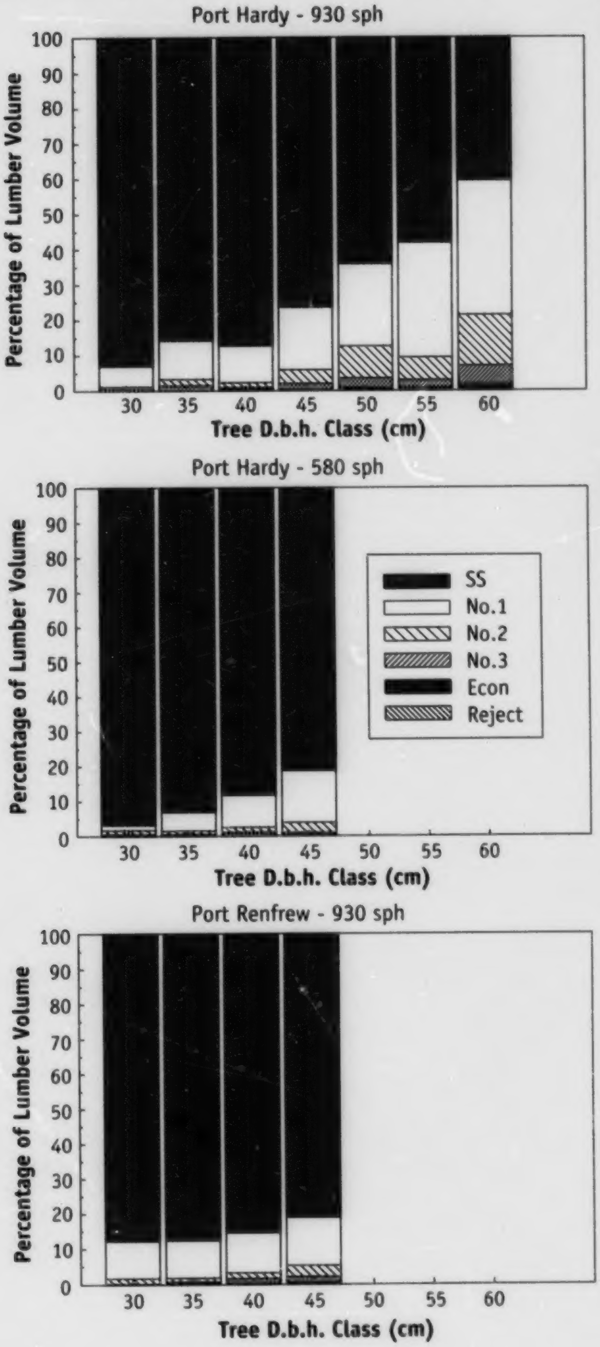


Table 2-21 *Percentage Distribution of Lumber Volume by JAS Grade Determining Knot Type*

JAS Knot Type	Stand			Total
	PH580	PH930	PR930	
Centre	11.3	12.5	10.5	11.4
Edge (Margin)	68.4	64.8	68.3	67.8
Narrow face (36 & 45 mm only)	13.6	18.9	17.7	15.0
Cluster	0.6	0.1	0.8	0.5
Group edge	1.8	1.2	0.8	1.6
Group centre	4.3	2.5	1.8	3.7
Total	100.0	100.0	100.0	100.0

Note: Tables 2-20 and 2-21 do not include lumber for which the knots make the top grade (JAS 1/SS)

Table 2-22 *Percentage Distribution of Lumber Volume by NLGA Grade Determining Knot Type*

NLGA Knot Type	Stand			Total
	PH580	PH930	PR930	
Centreline	35.6	25.3	28.5	34.2
Edge	47.7	50.9	47.5	47.9
Spike (36 & 45 mm only)	3.0	9.1	10.1	4.1
Cluster	5.9	5.7	6.4	5.9
Same x-sec'n/ Knots opposite	7.5	8.9	7.5	7.7
3-face	0.2	-	-	0.2
4-face	0.0	-	-	0.0
Total	100.0	100.0	100.0	100.0

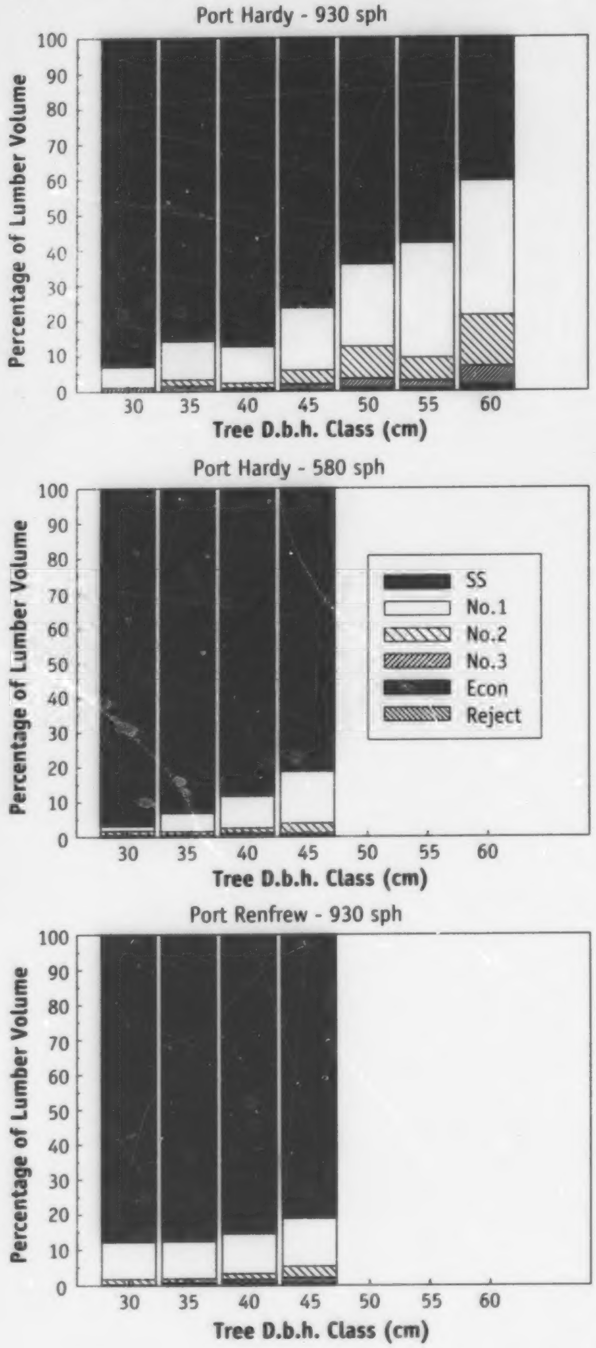
5 Conclusions

In terms of commercially important tree characteristics, stand density measured at 90 years of age discriminated between the most open stand, PH580, and the two more dense stands, PH930 and PR930. The PH580 stand contained larger diameter trees that were taller, had more taper, had larger crown ratios, more frequent and larger branches, and significantly lower average breast-height wood density. These characteristics are consistent with expectations for relatively open grown trees. PH580 had the highest site index.

Stand density measured at 90 years did not distinguish important differences between PH930 and PR930. These stands were nearly equivalent in stand density and site index, and range of most prevalent tree diameters. However, PH930 trees were somewhat taller, had a smaller crown ratio, and had branches that were smaller and less variable. PH930 trees also had a significantly lower average breast-height wood density.

Early growth rate proved to be a better measure than stand density for distinguishing important stand and tree characteristics. An evaluation of growth trends showed that average early growth rate was inversely related to average wood density. PR930 trees had the slowest early rate of

Figure 2-27
Distribution of NLGA Grade Determined by Knots Only



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Early growth rate proved to be a better measure than stand density for distinguishing important stand and tree characteristics. An evaluation of growth trends showed that average early growth rate was inversely related to average wood density. PR930 trees had the slowest early rate of growth, followed by PH930 trees. PH580 trees had the fastest early growth rate. Proportions by log volume of 15-ring and 30-ring juvenile wood were greatest in trees from PH580 and smallest in trees from PR930. Average breast-height wood density values for trees from PH930 equaled the species average and PR930 exceeded the species average. The extent to which site differences contributed to early growth rate could not be quantified.

Trends in early growth rates were described in sufficient detail to allow growth and yield experts to benchmark growth patterns found here with growth results associated with various stand-establishment densities.

PH580 trees yielded by far the highest proportion of relatively more valuable log grades. This reflects the fact that current log grade rules in British Columbia are determined largely on the basis of log diameter. Compared to old growth, western hemlock log grade yields from second growth will be much lower. How well current log grades distinguish value in second-growth hemlock depends not only on how well log grades estimate visual lumber grade proportions, but also on the extent to which strength values of second-growth lumber compare to those of old-growth.

Considered over the same log diameter classes, lumber recovery was highest for logs from PR930, and lower for logs from the PH580 and PH930 stands. These differences in recovery could not be attributed to differences in average log taper. Lumber recovery in general is likely underestimated in this study. Higher recovery results could be expected from a sawmill with modern optimization equipment.

The highest proportions of NLGA Select Structural, and JAS Grade No. 1 lumber were obtained from the PH930 stand. The lowest proportions were obtained from PH580. Select Structural and JAS No.1 grade percentages obtained from PH580 trees dropped noticeably as tree d.b.h. class increased to 60 cm. In general, lumber grade yields were highest when lumber was graded under NLGA rules rather than JAS rules, reflecting the more stringent JAS grade requirements.

When knots were considered as the only grade limiting criteria, the effect of increased knot size on both NLGA and JAS grades was apparent. There was a consistent reduction in premium lumber grade percentages for both grade rules as tree size class increased. Select Structural grade yield was reduced to only 41 percent of lumber from the 60 cm class at PH580. Increased branch size associated with rapid growth in low-density stands will significantly reduce proportions of premium lumber grades.

Various measures of knot size were evaluated in conjunction with log top diameter as a means to predict proportions of NLGA Select Structural and JAS No. 1 grade yields. Measured in terms of R^2, mean knot size, and the average of the four largest knots in a log, gave the best, but weak predictions of percent Select Structural. The R^2 value (.36) was equivalent to that obtained for a similar equation derived for lodgepole pine. Mean knot size ($R^2 = .28$) and the average of the largest knot in each log quadrant ($R^2 = .29$) gave the best results for predicting percent JAS Grade No. 1. Predictions of visual grade yields based on log diameter and knot size are tenuous at best.

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SECTION

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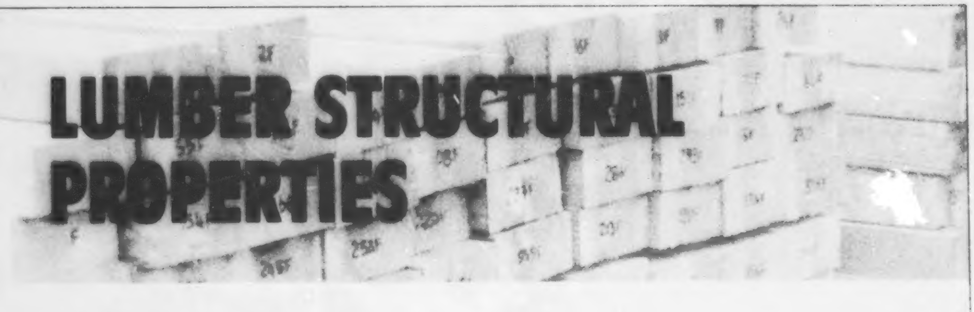

LUMBER STRUCTURAL PROPERTIES

G.R. Middleton, B.D. Munro and C. Lum

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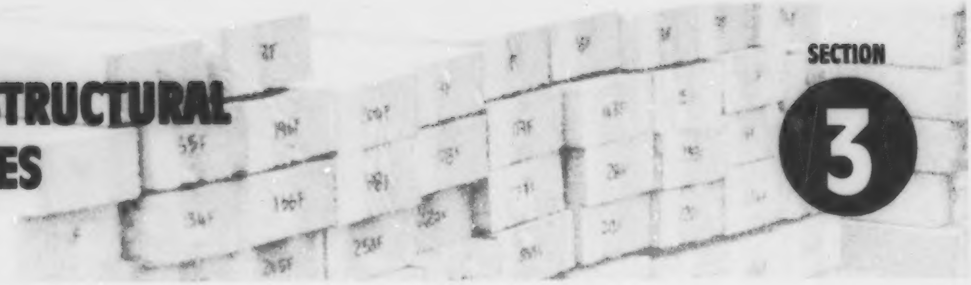
LUMBER STRUCTURAL PROPERTIES

SECTION 3



1 Introduction

There is limited information available on the mechanical properties of western hemlock lumber because it is generally combined with amabilis fir in grading rules and engineering design specifications. Littleford and Rovner (1968) determined the modulus of elasticity of utility, standard, construction and select structural grades of 2 x 4 and 2 x 8 western hemlock lumber. Foschi and Barrett (1982) investigated duration of load effects in 2 x 6 No. 2 and Better western hemlock.

There is even less information available on the mechanical properties of second-growth western hemlock. Studies of other species in British Columbia (Kellogg *et al.* 1989; Middleton *et al.* 1995) have shown that the mechanical properties of lumber from fast-grown second-growth trees can differ from those of lumber obtained from trees with slow or moderate rates of growth.

The purpose of this study was to evaluate the bending properties of full size lumber from second-growth western hemlock trees obtained from three stands of known site characteristics and stand density as previously described, and sawn to typical Japanese sizes.

2 Objective

To determine the mechanical properties of second-growth western hemlock and determine how these are influenced by differences in tree characteristics related to stand density.

3 Methods

Test Samples and Visual Grading

Dressed dry lumber was obtained from the conversion study described in Section 2. As previously described, the lumber was visually graded to the National Lumber Grades Authority (NLGA) rules for "Structural Light Framing" and "Structural Joist and Planks" (Para. 124). The samples were also graded to the Japanese Agricultural Standard (JAS) 143 visual grade rules for Type A Structural Lumber (bending). Lumber that showed signs of incipient decay related to duration of log storage was included in the tests[1] provided the piece could be positioned to avoid it.

During the visual grading, the grader identified visually the maximum strength-reducing characteristic (MSRC). The visual assessment of the MSRC took into account the amount of clear wood displaced by the characteristic(s), including the effect of any grain distortion. The assessment, however, did not consider whether the characteristic was on the tension or compression edge of the bending specimen.

Test Configuration and Procedure

Table 3-1 shows the distribution by dimension of all lumber tested. All samples were tested for bending stiffness and strength. These mechanical properties were determined from an edgewise bending under third-point loading and over a span corresponding to 18 times the nominal specimen depth.

Table 3-1 *Bending Test Sample*

Sample Size	Width[a] (mm)	Depth[b] (mm)	Bending Test Standard
194	36	90	ASTM D4761
147	45	90	ASTM D4761
193	**90**	**90**	**ASTM D198**
214	36	105	ASTM D4761
529	**45**	**105**	**ASTM D198**
1,846	**105**	**105**	**ASTM D198**
473	36	140	ASTM D4761
64	45	140	ASTM D4761
125	36	190	ASTM D4761
57	45	190	ASTM D4761

[a]Dimension perpendicular to the loading direction
[b]Dimension parallel to the loading direction

---

[1] MOE and MOR results were compared between lumber in which decay was present and avoided, and lumber that had no visible signs of decay. There was no consistent statistically significant difference in MOE or MOR between the two groups.

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SECTION

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For example, the distance between the centres of the outer supports was set to 1890 mm for the 45x105 mm sections; and the load points were located 630 mm from each end. For each size, a constant rate of displacement at the load points was selected such that the average time to failure ranged from 2 to 3 minutes. The bending modulus of elasticity (MOE) and modulus of rupture (MOR) were computed using the actual specimen's dimension at the time of the test.

Due to the wide range in cross-section widths, two bending test standards had to be used. As shown in Table 3-1, the two square cross-sections (90x90 mm and 105x105 mm) and the 45x105 mm cross-section were tested using a test set-up as described in ASTM D198. The remaining cross-sections were tested using a set-up compatible with ASTM D4761.

ASTM D198 and ASTM D4761 differ in the manner in which the deflection under load is measured for computing the specimen's modulus of elasticity. ASTM D198 requires a full span-yoke for determining the mid-span deflection of the specimen, while the ASTM D4761 permits the use of the average load point displacements for determining the modulus of elasticity. The ASTM D198 set-up was required for the square sections primarily because they could not be tested in Forintek's ASTM D4761 bending tester.

The modulus of elasticity results from the ASTM D4761 tests cannot be combined with the ASTM D198 results, unless the ASTM D4761 results are adjusted using the procedures in ASTM D2915, Section 4.3.

The ASTM D4761 modulus of elasticity results needed to be further corrected for "machine deflection" using the procedures described in Barrett and Lau (1994) - this adjustment which is specific to the Forintek bending tester typically reduces the ASTM D4761 modulus of elasticity result by approximately 1 to 2 percent. No adjustments for test configuration were required for the modulus of rupture results.

Mode of Failure, Wood Density and Moisture Content

Following the modulus of rupture tests the mode of failure was noted, and a full cross-section block approximately 30 mm long was taken from near the point of failure for each specimen. The relative density[2] was determined from these blocks. The oven-dried volume for determining the relative density was obtained by water immersion (ASTM D2395, Method B).

A number of the blocks were selected randomly from both the squares and the thinner dimensions and used to determine moisture content of the test sample. The moisture content was determined by weighing the blocks before and after oven-drying.

4 Results and Discussion

MOE and MOR statistics were summarized by NLGA structural grades, lumber dimension, and stand for all tree d.b.h. classes combined, and for individual tree d.b.h. classes. These results are appended, but should be considered and compared, only in the context of the sampling plan. The stands sampled were of predetermined stand density, and the sample trees were selected stratified by d.b.h. class. The results cannot be aggregated and construed to be representative of second-growth western hemlock in general.

MOE and MOR Related to Stand Density and Tree D.b.h. Class

Two lumber dimensions that represented the largest proportions of test material were chosen as the basis for comparing MOE and MOR results by stand and tree d.b.h. classes. These were the 105x105 mm squares and the 45x105 mm lumber.

Moisture Content

Lumber strength and stiffness properties are generally calculated at, or adjusted to, 15 percent moisture content. Average moisture content was determined for squares and side-cut lumber that were kiln dried to different target moisture contents. Moisture content was generally consistent for material compared by stands. The moisture content for the square material from Port Renfrew was slightly higher and more variable.

Table 3-2 *Moisture Content of Strength and Stiffness Test Material (%)*

Size		Stand			Combined
		PH580	PH930	PR930	
105x105	N	154	63	46	263
	MEAN	20.3	20.3	21.2	20.4
	STD	2.3	1.9	5.3	3.0
	CV[a]	11.3	9.4	24.8	14.5
	MIN	14.0	14.0	15.0	14.0
	MAX	32.0	27.0	49.0	49.0
45x90	N	100	28	18	146
	MEAN	15.2	15.1	15.5	15.2
	STD	0.9	1.0	0.7	0.9
	CV[a]	5.7	6.5	4.6	5.7
	MIN	13.0	13.0	15.0	13.0
	MAX	18.0	17.0	17.0	18.0
45x105	N	313	111	105	529
	MEAN	15.4	15.9	16.0	15.6
	STD	1.4	1.5	1.7	1.5
	CV[a]	9.3	9.3	10.8	9.8
	MIN	12.0	12.0	12.0	12.0
	MAX	19.0	23.0	21.0	23.0

[a] Coefficent of variation

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[2] In this instance wood density was calculated on an oven dry weight and oven dry volume basis.

Table 3-3 *Mean MOE and MOR for all Grades of 105x105 mm Squares*

TREE D.b.h. (cm)	Stand								
	PH580			PH930			PR930		
	N	MOR (psi)	MOE (x10⁶ psi)	N	MOR (psi)	MOE (x10⁶ psi)	N	MOR (psi)	MOE (x10⁶ psi)
30	12	8238	1.578	14	8669	1.797	11	8600	1.892
35	43	7806	1.656	47	9098	1.909	41	9273	2.001
40	124	7457	1.648	103	8342	1.790	89	9088	1.934
45	175	7740	1.660	140	8472	1.734	133	8941	1.950
50	231	7017	1.580	-	-	-	-	-	-
55	273	7184	1.574	-	-	-	-	-	-
60	410	6150	1.405	-	-	-	-	-	-
Combined	1268	6954	1.542	304	8534	1.783	274	9025	1.950

Table 3-2 provides moisture content statistics for the 105x105 mm squares and for 45x105 mm and 45x90 mm material. The mean moisture content for squares was approximately 20 percent. Moisture content of the 45x105 mm lumber was approximately 15 percent. The test results for the 105x105 mm squares were adjusted to 15 percent moisture content in accordance with ASTM D2915, Section 4.2.[3]

Mean MOE and MOR Values for All Grades Combined

Table 3-3 provides mean MOE and MOR values obtained for all grades of 105x105 mm squares compared by stand and tree d.b.h. class. MOE values are shown in Figure 3-1, and MOR values are shown in Figure 3-2. MOE and MOR values are highest for material obtained from PR930 followed by PH930, and values for PH580 are the lowest. Differences between stands were statistically significant. The effects of tree size were inconsistent, but large differences in d.b.h. resulted in significant differences in MOE and MOR.

Table 3-4 provides a similar comparison of mean MOE and MOR for 45x105 mm lumber. As illustrated in Figures 3-3 and 3-4, values remain highest for the PR930 trees followed again by the PH930. Values for PH580 are lowest. Differences between the 930 sph stands were not significant, but the PH580 values were significantly lower.

Mean MOE and MOR for Select Structural Lumber

Because large branch sizes associated with rapid tree growth are known to reduce lumber strength and stiffness properties, mean MOE and MOR values were further compared on the basis of Select Structural lumber only. The grade rule restricts knots by size and quality criteria and eliminates other indeterminate sources of variation possibly unrelated

Figure 3-1
Mean MOE by Stand and D.b.h. for all Grades of 105x105 mm Squares

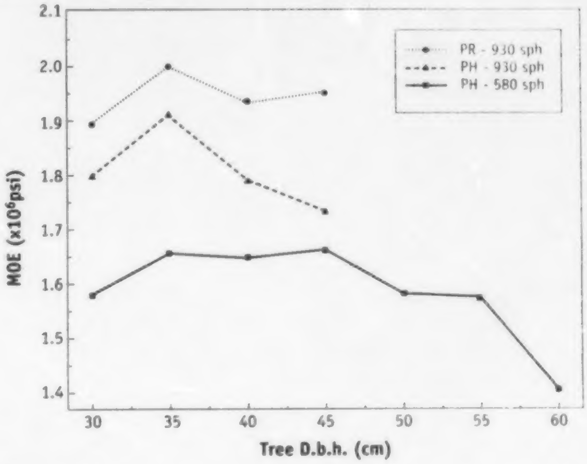
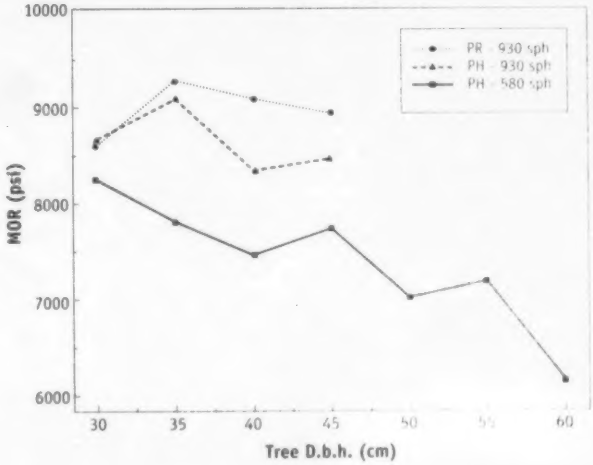


Figure 3-2
Mean MOR by Stand and D.b.h. for all Grades of 105x105 mm Squares



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[3] $MOE_{15\%} = MOE_{20\%}\ [1.44 - (0.020)(15)]/[1.44 - (0.020)(20)] = (1.0962)\ MOE_{20\%}$

$MOR_{15\%} = MOR_{20\%}\ [1.75 - (0.0333)(15)]/[1.75 - (0.0333)(20)] = (1.1536)\ MOR_{20\%}$

For example, the distance between the centres of the outer supports was set to 1890 mm for the 45x105 mm sections; and the load points were located 630 mm from each end. For each size, a constant rate of displacement at the load points was selected such that the average time to failure ranged from 2 to 3 minutes. The bending modulus of elasticity (MOE) and modulus of rupture (MOR) were computed using the actual specimen's dimension at the time of the test.

Due to the wide range in cross-section widths, two bending test standards had to be used. As shown in Table 3-1, the two square cross-sections (90x90 mm and 105x105 mm) and the 45x105 mm cross-section were tested using a test set-up as described in ASTM D198. The remaining cross-sections were tested using a set-up compatible with ASTM D4761.

ASTM D198 and ASTM D4761 differ in the manner in which the deflection under load is measured for computing the specimen's modulus of elasticity. ASTM D198 requires a full span-yoke for determining the mid-span deflection of the specimen, while the ASTM D4761 permits the use of the average load point displacements for determining the modulus of elasticity. The ASTM D198 set-up was required for the square sections primarily because they could not be tested in Forintek's ASTM D4761 bending tester.

The modulus of elasticity results from the ASTM D4761 tests cannot be combined with the ASTM D198 results, unless the ASTM D4761 results are adjusted using the procedures in ASTM D2915, Section 4.3.

The ASTM D4761 modulus of elasticity results needed to be further corrected for "machine deflection" using the procedures described in Barrett and Lau (1994) – this adjustment which is specific to the Forintek bending tester typically reduces the ASTM D4761 modulus of elasticity result by approximately 1 to 2 percent. No adjustments for test configuration were required for the modulus of rupture results.

Mode of Failure, Wood Density and Moisture Content

Following the modulus of rupture tests the mode of failure was noted, and a full cross-section block approximately 30 mm long was taken from near the point of failure for each specimen. The relative density[2] was determined from these blocks. The oven-dried volume for determining the relative density was obtained by water immersion (ASTM D2395, Method B).

A number of the blocks were selected randomly from both the squares and the thinner dimensions and used to determine moisture content of the test sample. The moisture content was determined by weighing the blocks before and after oven-drying.

4 Results and Discussion

MOE and MOR statistics were summarized by NLGA structural grades, lumber dimension, and stand for all tree d.b.h. classes combined, and for individual tree d.b.h. classes. These results are appended, but should be considered and compared, only in the context of the sampling plan. The stands sampled were of predetermined stand density, and the sample trees were selected stratified by d.b.h. class. The results cannot be aggregated and construed to be representative of second-growth western hemlock in general.

MOE and MOR Related to Stand Density and Tree D.b.h. Class

Two lumber dimensions that represented the largest proportions of test material were chosen as the basis for comparing MOE and MOR results by stand and tree d.b.h. classes. These were the 105x105 mm squares and the 45x105 mm lumber.

Moisture Content

Lumber strength and stiffness properties are generally calculated at, or adjusted to, 15 percent moisture content. Average moisture content was determined for squares and side-cut lumber that were kiln dried to different target moisture contents. Moisture content was generally consistent for material compared by stands. The moisture content for the square material from Port Renfrew was slightly higher and more variable.

Table 3-2 *Moisture Content of Strength and Stiffness Test Material (%)*

Size		Stand			Combined
		PH580	PH930	PR930	
105x105	N	154	63	46	263
	MEAN	20.3	20.3	21.2	20.4
	STD	2.3	1.9	5.3	3.0
	CV[a]	11.3	9.4	24.8	14.5
	MIN	14.0	14.0	15.0	14.0
	MAX	32.0	27.0	49.0	49.0
45x90	N	100	28	18	146
	MEAN	15.2	15.1	15.5	15.2
	STD	0.9	1.0	0.7	0.9
	CV[a]	5.7	6.5	4.6	5.7
	MIN	13.0	13.0	15.0	13.0
	MAX	18.0	17.0	17.0	18.0
45x105	N	313	111	105	529
	MEAN	15.4	15.9	16.0	15.6
	STD	1.4	1.5	1.7	1.5
	CV[a]	9.3	9.3	10.8	9.8
	MIN	12.0	12.0	12.0	12.0
	MAX	19.0	23.0	21.0	23.0

[a] Coefficent of variation

---

[2] In this instance wood density was calculated on an oven dry weight and oven dry volume basis.

Table 3-3 *Mean MOE and MOR for all Grades of 105x105 mm Squares*

TREE D.b.h. (cm)	Stand								
	PH580			PH930			PR930		
	N	MOR (psi)	MOE ($\times 10^6$ psi)	N	MOR (psi)	MOE ($\times 10^6$ psi)	N	MOR (psi)	MOE ($\times 10^6$ psi)
30	12	8238	1.578	14	8669	1.797	11	8600	1.892
35	43	7806	1.656	47	9098	1.909	41	9273	2.001
40	124	7457	1.648	103	8342	1.790	89	9088	1.934
45	175	7740	1.660	140	8472	1.734	133	8941	1.950
50	231	7017	1.580	-	-	-	-	-	-
55	273	7184	1.574	-	-	-	-	-	-
60	410	6150	1.405	-	-	-	-	-	-
Combined	1268	6954	1.542	304	8534	1.783	274	9025	1.950

Table 3-2 provides moisture content statistics for the 105x105 mm squares and for 45x105 mm and 45x90 mm material. The mean moisture content for squares was approximately 20 percent. Moisture content of the 45x105 mm lumber was approximately 15 percent. The test results for the 105x105 mm squares were adjusted to 15 percent moisture content in accordance with ASTM D2915, Section 4.2.[3]

Mean MOE and MOR Values for All Grades Combined

Table 3-3 provides mean MOE and MOR values obtained for all grades of 105x105 mm squares compared by stand and tree d.b.h. class. MOE values are shown in Figure 3-1, and MOR values are shown in Figure 3-2. MOE and MOR values are highest for material obtained from PR930 followed by PH930, and values for PH580 are the lowest. Differences between stands were statistically significant. The effects of tree size were inconsistent, but large differences in d.b.h. resulted in significant differences in MOE and MOR.

Table 3-4 provides a similar comparison of mean MOE and MOR for 45x105 mm lumber. As illustrated in Figures 3-3 and 3-4, values remain highest for the PR930 trees followed again by the PH930. Values for PH580 are lowest. Differences between the 930 sph stands were not significant, but the PH580 values were significantly lower.

Mean MOE and MOR for Select Structural Lumber

Because large branch sizes associated with rapid tree growth are known to reduce lumber strength and stiffness properties, mean MOE and MOR values were further compared on the basis of Select Structural lumber only. The grade rule restricts knots by size and quality criteria and eliminates other indeterminate sources of variation possibly unrelated

Figure 3-1
Mean MOE by Stand and D.b.h. for all Grades of 105x105 mm Squares

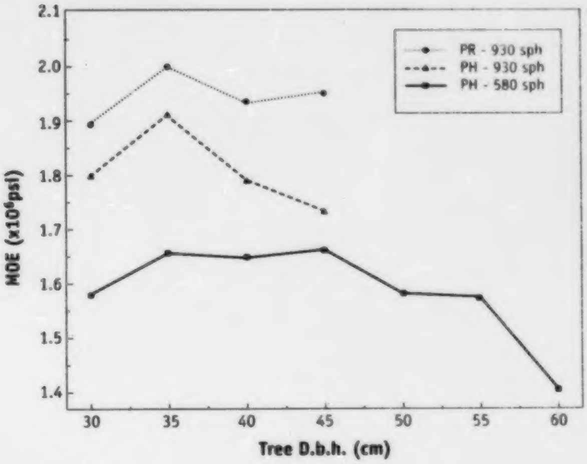
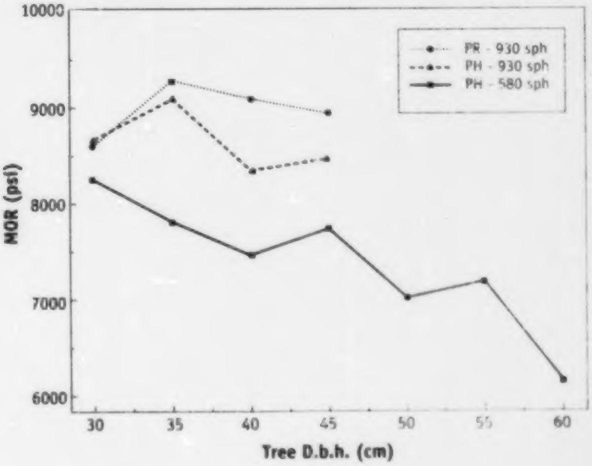


Figure 3-2
Mean MOR by Stand and D.b.h. for all Grades of 105x105 mm Squares



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[3] $MOE_{15\%} = MOE_{20\%}\ [1.44 - (0.020)(15)]/[1.44 - (0.020)(20)]$

$= (1.0962)\ MOE_{20\%}$

$MOR_{15\%} = MOR_{20\%}\ [1.75 - (0.0333)(15)]/[1.75 - (0.0333)(20)]$

$= (1.1536)\ MOR_{20\%}$

to tree growth such as mis-manufacture. Table 3-5 provides MOE and MOR results for 105x105 mm squares, and Table 3-6 provides these results for 45x105 mm lumber. Figure 3-5 and Figure 3-6 show trends for 105x105 mm squares by d.b.h. class for each stand, and Figure 3-7 and Figure 3-8 show these trends for 45x105 mm lumber.

Table 3-4 *Mean MOE and MOR for all Grades of 45x105 mm Lumber*

TREE D.b.h. (cm)	Stand								
	PH580			PH930			PR930		
	N	MOR (psi)	MOE ($x10^6$ psi)	N	MOR (psi)	MOE ($x10^6$ psi)	N	MOR (psi)	MOE ($x10^6$ psi)
30	10	7098	1.572	6	7532	1.674	8	8609	1.840
35	21	6648	1.619	28	8732	1.921	26	8693	2.040
40	40	7011	1.662	37	7584	1.808	27	8088	1.779
45	41	7328	1.712	40	7955	1.867	44	8185	1.881
50	62	6907	1.640	-	-	-	-	-	-
55	69	7447	1.703	-	-	-	-	-	-
60	70	6224	1.547	-	-	-	-	-	-
Combined	313	6931	1.642	111	8004	1.851	105	8318	1.891

Figure 3-3

Mean MOE by Stand and D.b.h. for all Grades of 45x105 mm Lumber

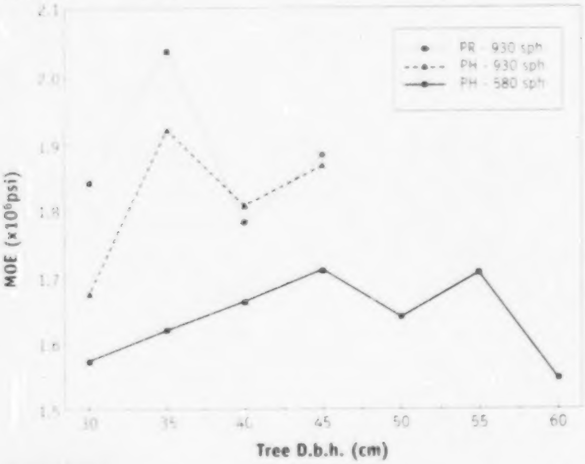


Figure 3-4

Mean MOR by Stand and D.b.h. for all Grades of 45x105 mm Lumber

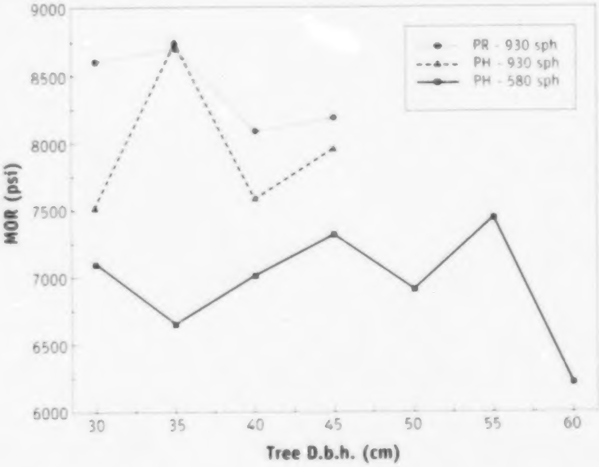


Table 3-5 *Mean MOE and MOR for 105x105 mm Select Structural Squares*

TREE D.b.h. (cm)	Stand								
	PH580			PH930			PR930		
	N	MOR (psi)	MOE ($x10^6$ psi)	N	MOR (psi)	MOE ($x10^6$ psi)	N	MOR (psi)	MOE ($x10^6$ psi)
30	9	8389	1.601	12	8386	1.762	8	8965	1.928
35	33	8074	1.681	42	9152	1.909	23	9979	2.053
40	97	7457	1.625	76	8710	1.814	62	9208	1.958
45	124	7905	1.664	110	8683	1.749	100	8899	1.948
50	135	7191	1.601	-	-	-	-	-	-
55	123	7415	1.556	-	-	-	-	-	-
60	127	6791	1.434	-	-	-	-	-	-
Combined	648	7393	1.579	240	8759	1.798	193	9130	1.963

Table 3-6 *Mean MOE and MOR for 45x105 mm Select Structural Lumber*

Tree D.b.h.	Stand								
	PH580			PH930			PR930		
	N	MOR (psi)	MOE ($\times 10^6$ psi)	N	MOR (psi)	MOE ($\times 10^6$ psi)	N	MOR (psi)	MOE ($\times 10^6$ psi)
30	7	6249	1.565	4	8375	1.774	7	8863	1.894
35	9	7332	1.682	22	8936	1.943	15	9997	2.157
40	13	6412	1.603	18	8301	1.934	12	9720	1.922
45	10	8933	1.810	15	9443	2.006	19	8904	1.927
50	16	8184	1.712	-	-	-	-	-	-
55	19	8860	1.884	-	-	-	-	-	-
60	10	7351	1.681	-	-	-	-	-	-
Combined	84	7800	1.727	59	8833	1.945	53	9393	1.987

Figure 3-5
Mean MOE by Stand and D.b.h. for 105x105 mm Select Structural Squares

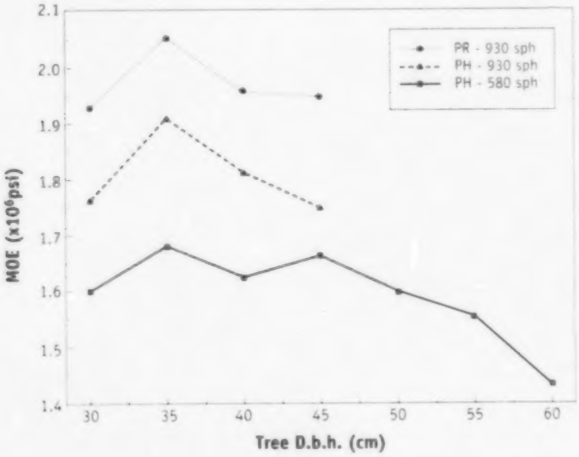


Figure 3-6
Mean MOR by Stand and D.b.h. for 105x105 mm Select Structural Squares

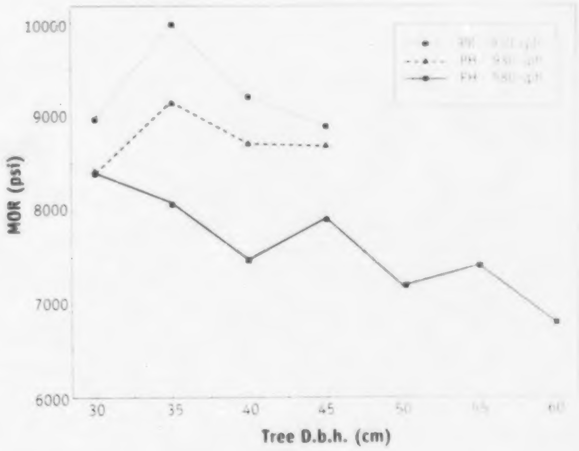


Figure 3-7
Mean MOE by Stand and D.b.h. for 45x105 mm Select Structural Lumber

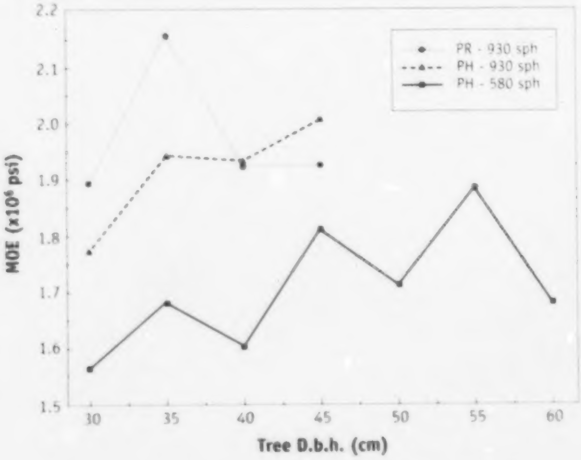
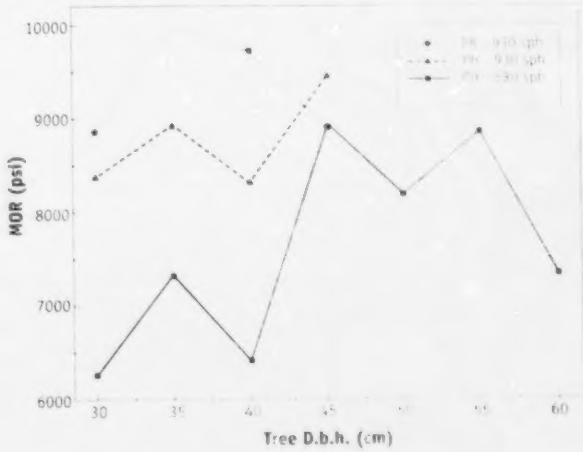


Figure 3-8
Mean MOR by Stand and D.b.h. for 45x105 mm Select Structural Lumber



to tree growth such as mis-manufacture. Table 3-5 provides MOE and MOR results for 105x105 mm squares, and Table 3-6 provides these results for 45x105 mm lumber. Figure 3-5 and Figure 3-6 show trends for 105x105 mm squares by d.b.h. class for each stand, and Figure 3-7 and Figure 3-8 show these trends for 45x105 mm lumber.

Table 3-4 *Mean MOE and MOR for all Grades of 45x105 mm Lumber*

TREE D.b.h. (cm)	Stand								
	PH580			PH930			PR930		
	N	MOR (psi)	MOE (x10⁶ psi)	N	MOR (psi)	MOE (x10⁶ psi)	N	MOR (psi)	MOE (x10⁶ psi)
30	10	7098	1.572	6	7532	1.674	8	8609	1.840
35	21	6648	1.619	28	8732	1.921	26	8693	2.040
40	40	7011	1.662	37	7584	1.808	27	8088	1.779
45	41	7328	1.712	40	7955	1.867	44	8185	1.881
50	62	6907	1.640	-	-	-	-	-	-
55	69	7447	1.703	-	-	-	-	-	-
60	70	6224	1.547	-	-	-	-	-	-
Combined	313	6931	1.642	111	8004	1.851	105	8318	1.891

Figure 3-3
Mean MOE by Stand and D.b.h. for all Grades of 45x105 mm Lumber

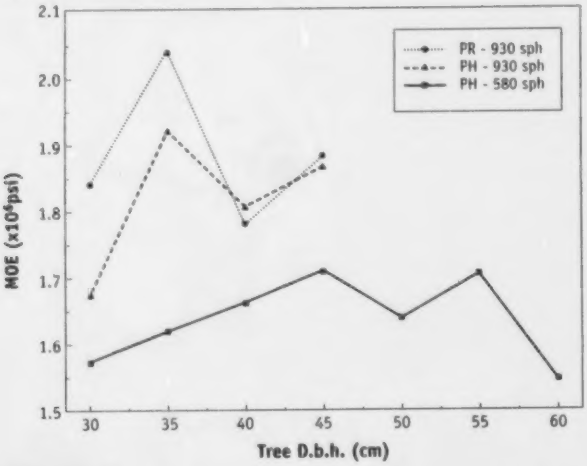
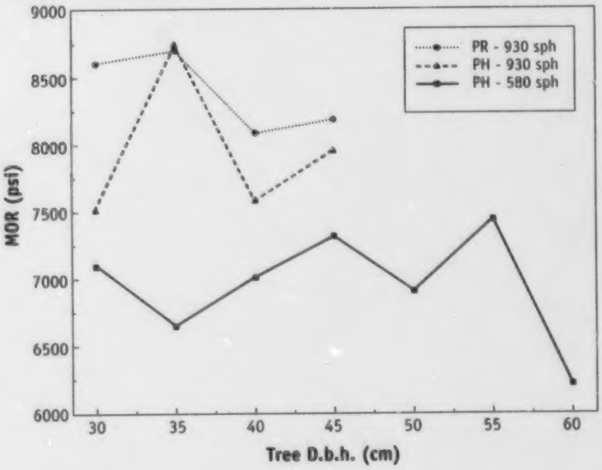


Figure 3-4
Mean MOR by Stand and D.b.h. for all Grades of 45x105 mm Lumber



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TREE D.b.h. (cm)	Stand								
	PH580			PH930			PR930		
	N	MOR (psi)	MOE (x10⁶ psi)	N	MOR (psi)	MOE (x10⁶ psi)	N	MOR (psi)	MOE (x10⁶ psi)
30	9	8389	1.601	12	8386	1.762	8	8965	1.928
35	33	8074	1.681	42	9152	1.909	23	9979	2.053
40	97	7457	1.625	76	8710	1.814	62	9208	1.958
45	124	7905	1.664	110	8683	1.749	100	8899	1.948
50	135	7191	1.601	-	-	-	-	-	-
55	123	7415	1.556	-	-	-	-	-	-
60	127	6791	1.434	-	-	-	-	-	-
Combined	648	7393	1.579	240	8759	1.798	193	9130	1.963

Table 3-6 *Mean MOE and MOR for 45x105 mm Select Structural Lumber*

Tree D.b.h.	**Stand**								
	PH580			**PH930**			**PR930**		
	N	**MOR (psi)**	**MOE (x10⁶ psi)**	**N**	**MOR (psi)**	**MOE (x10⁶ psi)**	**N**	**MOR (psi)**	**MOE (x10⁶ psi)**
30	7	6249	1.565	4	8375	1.774	7	8863	1.894
35	9	7332	1.682	22	8936	1.943	15	9997	2.157
40	13	6412	1.603	18	8301	1.934	12	9720	1.922
45	10	8933	1.810	15	9443	2.006	19	8904	1.927
50	16	8184	1.712	-	-	-	-	-	-
55	19	8860	1.884	-	-	-	-	-	-
60	10	7351	1.681	-	-	-	-	-	-
Combined	84	7800	1.727	59	8833	1.945	53	9393	1.987

Figure 3-5
Mean MOE by Stand and D.b.h. for 105x105 mm Select Structural Squares

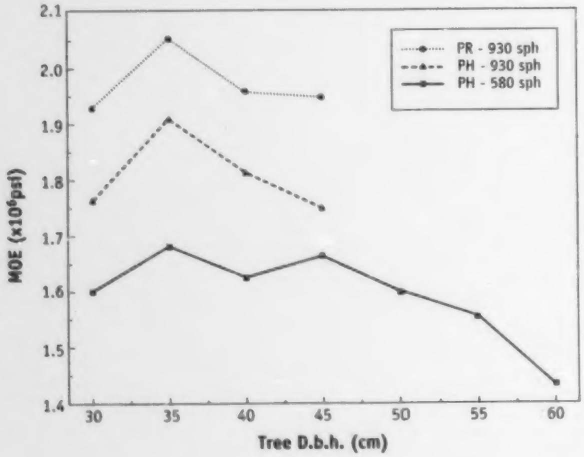


Figure 3-6
Mean MOR by Stand and D.b.h. for 105x105 mm Select Structural Squares

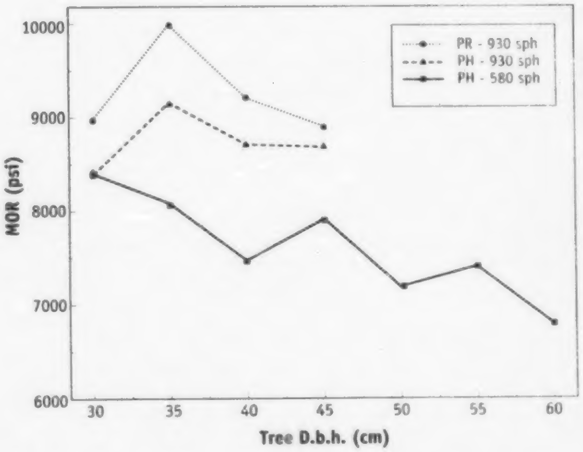


Figure 3-7
Mean MOE by Stand and D.b.h. for 45x105 mm Select Structural Lumber

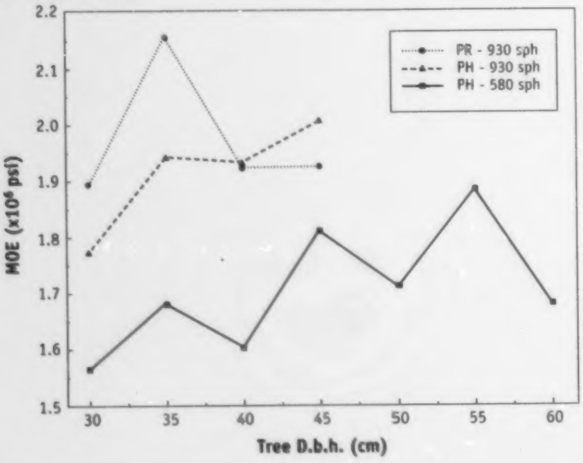
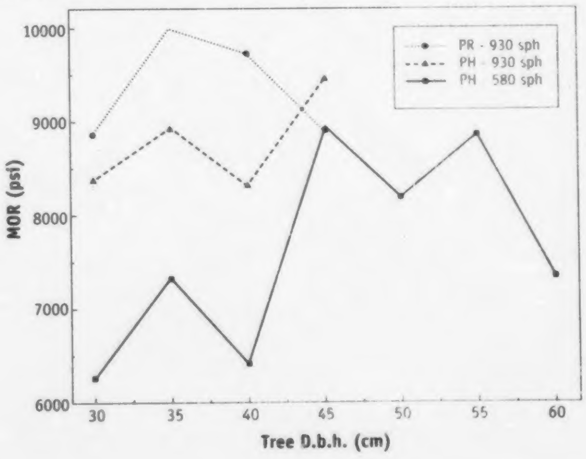


Figure 3-8
Mean MOR by Stand and D.b.h. for 45x105 mm Select Structural Lumber



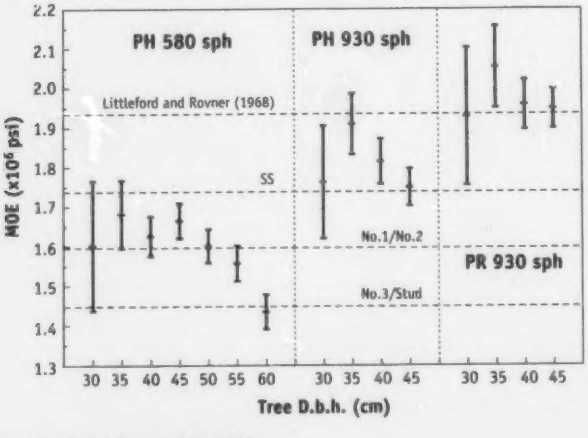
Differences in MOE and MOR between stands were significant at the 0.0001 level. Differences related to d.b.h. were not significant.

Mean MOE Compared to Old Growth Western Hemlock and Hem-Fir Design Values

Figure 3-9 illustrates mean MOE and 95 percent confidence intervals for Select Structural 105x105 mm squares by stand and d.b.h. class. These are shown compared to present design values[4] for Hem-Fir (Canadian Standard 086.1-94), and to an old-growth value for western hemlock (Littleford and Rovner, 1968). The large confidence intervals for mean values in the 30 cm d.b.h. classes reflect the limited sample sizes. A complete summary of MOE statistics is appended.

Mean MOE values for PR930 generally exceed, but were not significantly greater than, the old-growth value. Confidence intervals for these mean values are above the design value for Hem-Fir Select Structural lumber for all d.b.h. classes. Those for PH930 are above or include design value. Mean MOE values for PH580 fall entirely below the Select Structural design value and for 40 cm and larger d.b.h. classes so do the confidence intervals. The mean MOE of the 60 cm d.b.h. class from PH580 corresponds to the design value for No. 3 as indicated by the confidence interval.

Figure 3-9
Mean MOE and 95 Percent Confidence Intervals for Select Structural 105x105 mm Squares Compared to Hem-Fir Design Values and to MOE for Select Structural Old-growth Western Hemlock



Mean and 5th Percentile MOR

Figure 3-10 illustrates mean MOR and 95 percent confidence intervals for Select Structural 105x105 mm squares by stand and d.b.h. class. The large confidence intervals for mean values in the 30 cm d.b.h. classes reflect the more limited sample sizes. Comparative values for mean MOR were not available because it is the 5th percentile of bending MOR that is of primary importance to structural engineers.

Figure 3-10
Mean MOR and 95 Percent Confidence Intervals for Select Structural 105x105 mm Squares

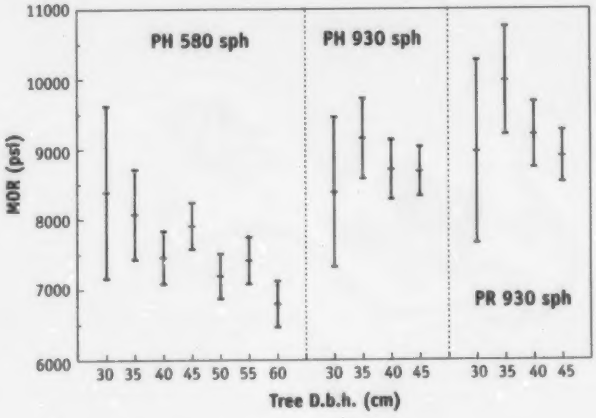


Figure 3-11
5th Percentile MOR and 95 Percent Confidence Intervals for Select Structural 105x105 mm Squares and Hem-Fir Design Value

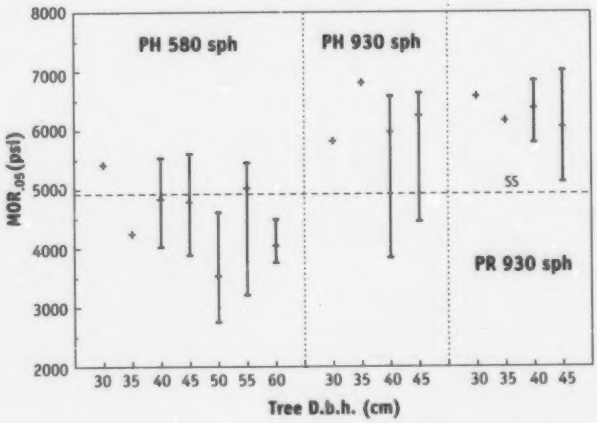


Figure 3-11 illustrates 5th percentile MOR values and 95 percent confidence intervals for the three stands by tree d.b.h. class. A summary of 5th percentile MOR statistics is appended. The 5th percentile is the non-parametric point estimate and the 95 percent confidence intervals are non-parametric (Cook, 1986). This figure demonstrates the limitations of the lumber samples when distributed by tree size class. The 95 percent confidence interval cannot always be obtained because this non-parametric test requires minimum samples sizes for choosing lower and upper confidence limits as ranked pairs of observations for which the interval comes closest to the desired level of confidence. Lower levels of confidence that were obtained are included in the Appendix.

---

[4] MOE values shown are the specified modulus-of-elasticity for the grade groups (CAN/CSA - 086.1 - 94).

Compared stand-to-stand, the 5th percentile point estimates and confidence intervals in Figure 3-11 show a trend similar to that obtained for mean MOE. Note that the confidence intervals for 5th percentile point estimates obtained for three d.b.h. classes in the PH580 stand include the Select Structural design value[5]. In general, lumber from the PH580 stand that was visually graded Select Structural came closer to meeting the design value for MOR than for MOE.

Comparisons to Design Values

The comparisons made to MOE and MOR design values above have to be qualified. In assigning design values to a species or species group (Hem-Fir) the "package" of lumber tested is obtained by random selection of lumber from many sources such that the tests are considered representative of the full population. In this study the "Fir" component (amabilis fir) was excluded, and the western hemlock obtained was not typical of the western hemlock resource in general. The stands and sample trees were selected, not at random, but to reflect possible outcomes of stand density management. Thus, the results of the engineering tests described above do not apply to western hemlock in general, and comparisons to Hem-Fir design values are not strictly valid.

Design values for lumber grades are not established to compare the performance of individual pieces of lumber, nor of small samples such as those obtained from the three stands in this study. The fact that lumber from the PH580 stand "falls below" the design value does not invalidate the grade assigned. The overall population for which the design value was determined could be expected to contain similar material. The lower average strength and stiffness properties obtained for lumber from PH580 would only have an influence on design values if large quantities of similar lumber became part of the total hemlock lumber population.

Influence of Tree Position on MOE, MOR and Wood Density

Manufacturers of wood products are interested in the potential to sort logs for allocation to various manufacturing processes that will maximize total value. Figures 3-12 and 3-13 show MOE and MOR values by stand for 105x105 mm squares sorted by saw-log position in the stem as counted from the bottom of the tree. Saw logs were 4 m long.

Figure 3-12

Mean MOE Values for 105x105 mm Squares by Tree Stem Location

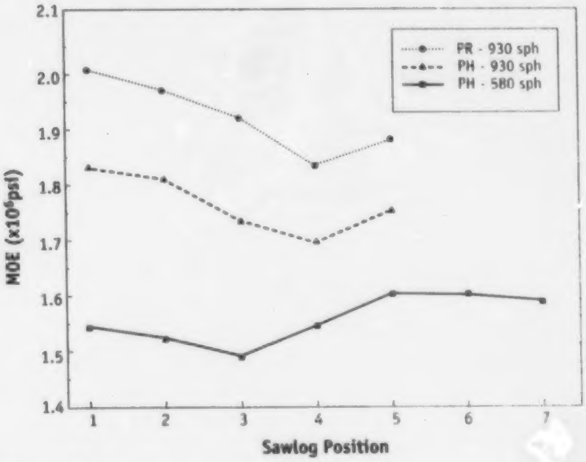
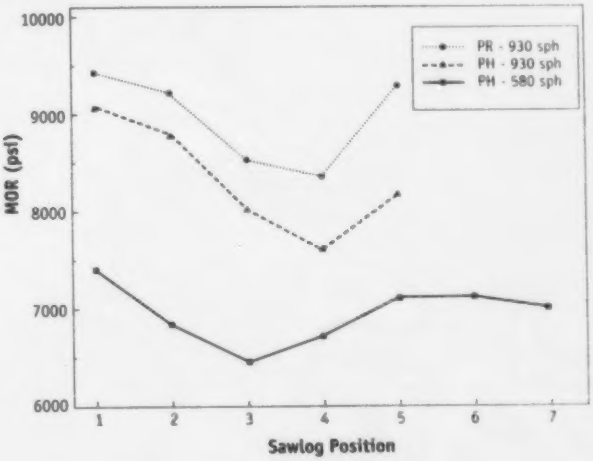


Figure 3-13

Mean MOR Values for 105x105 mm Squares by Tree Stem Location



Except for MOE in the PH580 sample, MOE and MOR values were generally highest in butt logs. In the PH930 and PR930 samples these values declined to the 4th log position and were higher in log number 5. In the PH580 sample the decline in mean values ended with log number 3, values increased to log number 5 and declined slightly in logs 6 and 7. Note that because the small log sample was not converted to lumber the tree crown position is generally not represented in the MOE and MOR trends by tree position. The last log position (number 5 for the PH930 and PR930 stands) extended 20 m up the tree. The last log position for PH580 extended 28 m. The average height to the base of the live crowns was approximately 25 m in the PH580 and PH930 stands, and about 20 m in the PR930 stand.

The trends in MOE and MOR by stem position correspond to a similar trend in the wood density[6] of the squares as illustrated in Figure 3-14. The fact that density continues to trend upward beyond log position 5 in the PH580 sample

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[5] Derived conservatively from the specified bending strength for Hem-Fir Select Structural (CAN/CSA – 086.1-94) adjusted for load duration (1 to 10 minute test) and piece size (closest comparable NLGA size 89 x 89 mm).

[6] Density values were calculated on an oven dry weight, and oven dry volume basis at point of failure for the squares tested.

Figure 3-14
Wood Density Trends by Tree Stem Position

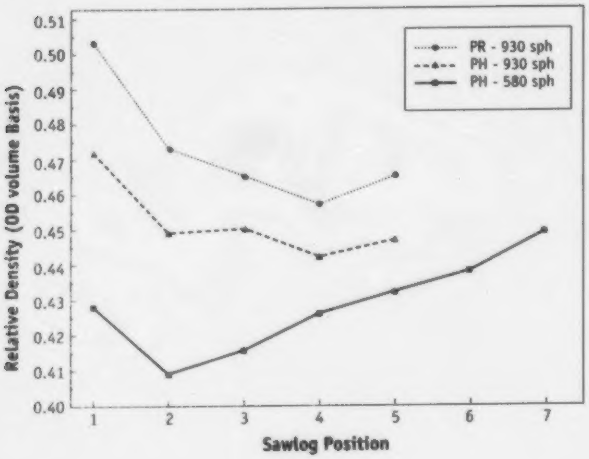


Figure 3-15
MOE for Select Structural 105x105 mm Squares Related to Proportion of Piece Volume Within 15 Rings of the Pith

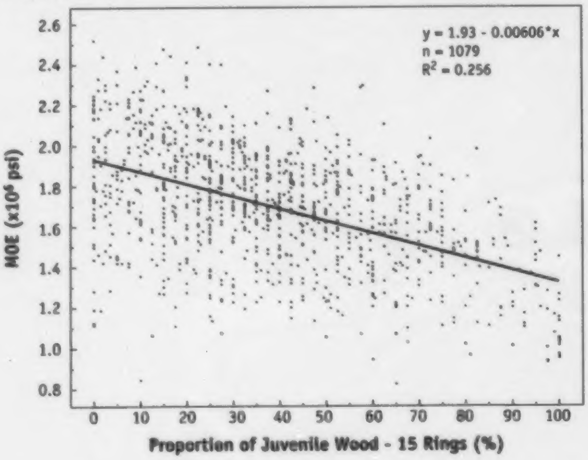
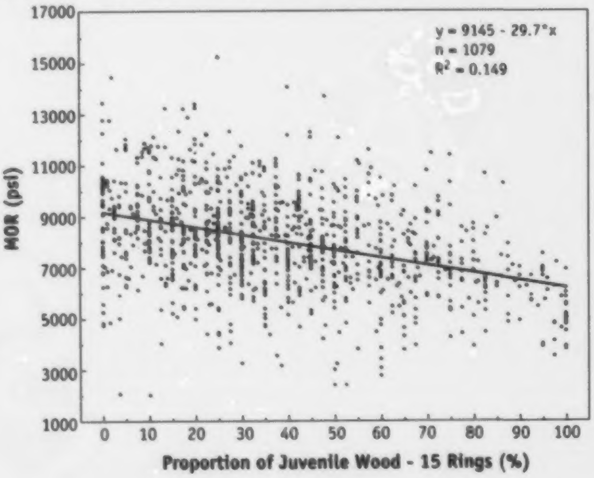


Figure 3-16
MOR for Select Structural 105x105 mm Squares Related to Proportion of Piece Volume Within 15 Rings of the Pith



while MOE and MOR had begun to decline suggests that knots in near crown positions were beginning to have increased influence on strength and stiffness.

Jozsa *et al* (1998) also reported that average wood density was initially high at the bottom of second-growth western hemlock trees, and generally declined to 20 percent of tree height. It continued to decline somewhat or remained relatively constant to 70 percent of tree height, and then increased to the 90 percent position. Their evaluation included trees selected from the three stands evaluated in this study.

Lumber MOE and MOR Related to Juvenile Wood

Juvenile wood zones of 15 and 30 annual rings counted from the pith were marked on logs and remained visible on the ends of sample lumber as previously described. Estimates of the proportion of lumber piece volume contained within each juvenile zone were related to MOE and MOR values for each piece.

Relationships between MOE and MOR and the proportions of first 15-ring wood in Select Structural 105x105 mm squares are illustrated in Figures 3-15 and 3-16 respectively. Results of regression analyses are provided on the graphs. Proportions of juvenile wood proved significant, but in terms of R^2 explained only 26 and 15 percent of the variation in MOE and MOR respectively.

Substituting proportions of first 30-ring wood for first 15-ring wood reduced R^2 for both MOE and MOR as shown in Figures 3-17 and 3-18. It also had the effect of shifting specimens higher on the scale of juvenile wood proportion. The scatter graphs show that few squares had low proportions of juvenile wood under the 30-ring definition.

Given the results of a similar evaluation in lodgepole pine (Middleton *et al.* 1995), fixed ring counts were not expected to provide definitive definitions of juvenile wood. Defining juvenile wood in terms of a fixed ring count is expedient for the purposes of modelling internal tree structure, but the juvenile zone varies substantially from tree to tree even when defined merely in the terms of wood density. Furthermore, we know that wood density is only one factor contributing to the lower strength and stiffness properties associated with juvenile wood.

Juvenile wood zones defined by the number of rings from the pith proved to be poor predictors of strength and stiffness for individual pieces of lumber, but their relationships to MOE and MOR were highly significant. An approach taken by Kellogg *et al* (1989) was to determine mean MOE and MOR values for lumber segregated into discrete juvenile wood classes.

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Figure 3-17

MOE for Select Structural 105x105 mm Squares Related to Proportion of Piece Volume Within 30 Rings of the Pith

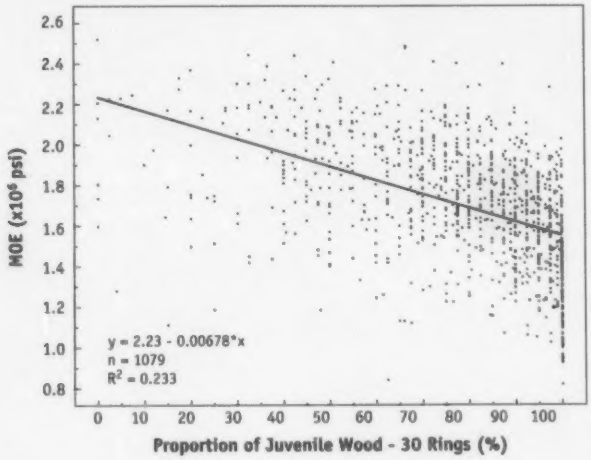

Figure 3-18

MOR for Select Structural 105x105 mm Squares Related to Proportion of Piece Volume Within 30 Rings of the Pith

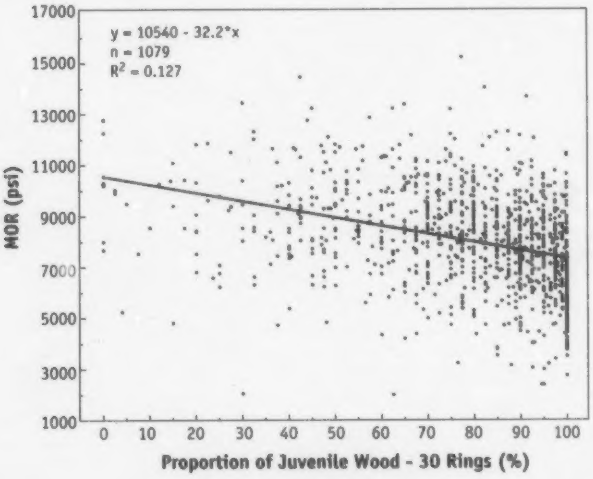

Table 3-7 provides MOE and MOR statistics for Select Structural squares segregated into five 20 percent classes of 15-ring and 30-ring proportions. The results are illustrated in Figures 3-19 and 3-20.

The first 15-rings from the pith proved to be the more detrimental definition of juvenile wood in terms of mean MOE and MOR. Differences in mean MOE and MOR values between the discrete juvenile wood classes were all significant. Mean MOE and MOR values were generally higher when the juvenile wood zone was defined as wood within the first 30-rings, and differences between the three 30-ring classes that had the lowest proportions of juvenile wood were not significant. Mean values for two lowest classes were significantly higher than those in the 61 to 80 percent class. Values for the latter class were not significantly different from those of 41 to 60 percent class. Mean values for the 81-100 percent juvenile wood class were significantly lower then those in all other classes.

Table 3-7 *MOE and MOR for Select Structural 105x105 mm Squares Classified by 15 and 30 Ring Volume Proportions*

Juvenile Wood Class (% Vol.)	No. of Pieces	MOR (psi)		MOE (x10⁶ psi)	
		MEAN	STD	MEAN	STD
15 Rings					
0 - 20	307	8786	1932	1.852	0.300
21 - 40	322	8203	1797	1.744	0.246
41 - 60	243	7806	1846	1.649	0.252
61 - 80	134	7209	1567	1.537	0.236
81 - 100	75	6048	1341	1.296	0.235
30 Rings					
0 - 20	29	9252	1849	1.918	0.338
21 - 40	47	8682	2110	1.931	0.293
41 - 60	120	9083	1772	1.896	0.265
61 - 80	279	8601	1839	1.811	0.254
81 - 100	606	7408	1776	1.575	0.268

Lumber MOE and MOR Related to Breast-Height Diameter and Wood Density

Middleton, *et al.* (1995) investigated the possibility of predicting average lumber MOE and MOR for individual lodgepole pine trees on the basis of breast-height wood density, d.b.h. and average knot size. In that study, complete trees were converted to dimension lumber.

A similar study was made of the potential for using breast-height wood density and d.b.h. to predict lumber strength and stiffness properties of second-growth western hemlock squares.

MOE and MOR values obtained for individual 105x105 mm squares of all visual grades were averaged for each of the first long logs in each tree and considered as dependent variables in stepwise regressions. Breast-height wood density proved significant at the .0001 level and contributed most to "explained" variation in both MOE and MOR. Diameter at breast height was significant at the .0070 level for MOE and .0026 level for MOR, but as indicated by partial R^2, contributed little to explained variation.

Figure 3-17
MOE for Select Structural 105x105 mm Squares Related to Proportion of Piece Volume Within 30 Rings of the Pith

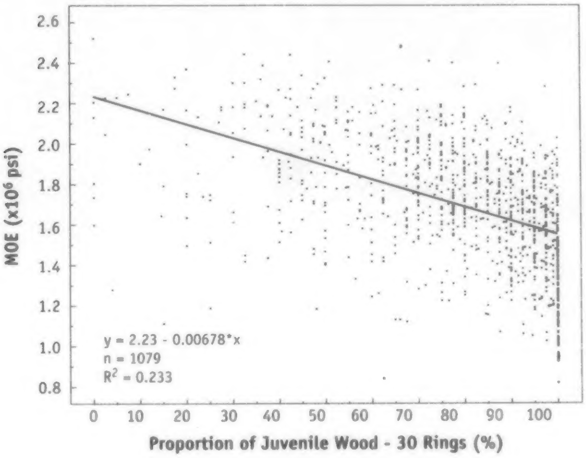

Figure 3-18
MOR for Select Structural 105x105 mm Squares Related to Proportion of Piece Volume Within 30 Rings of the Pith

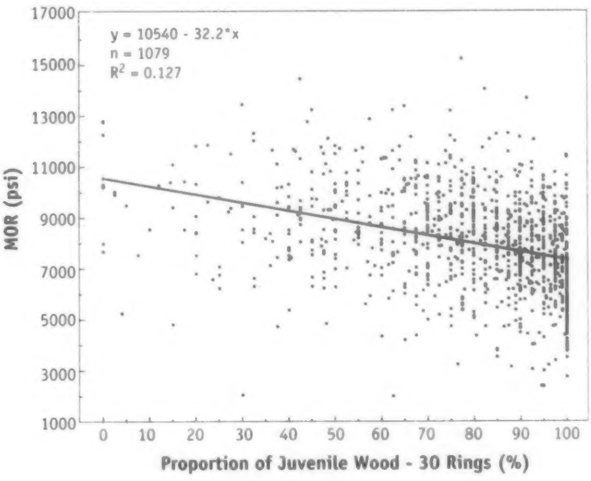

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Figure 3-19

Mean MOE for 105x105 mm Select Structural Squares Related to Juvenile Wood Class

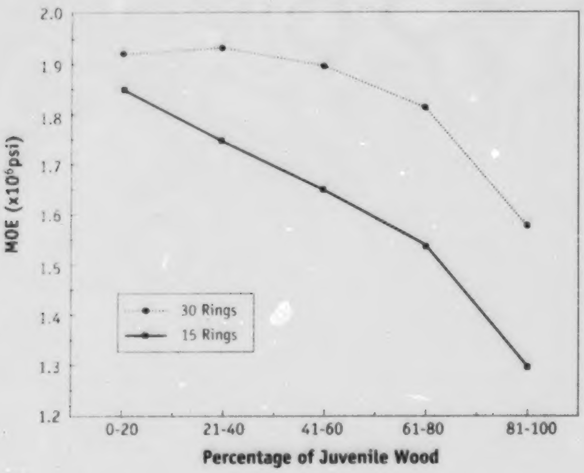
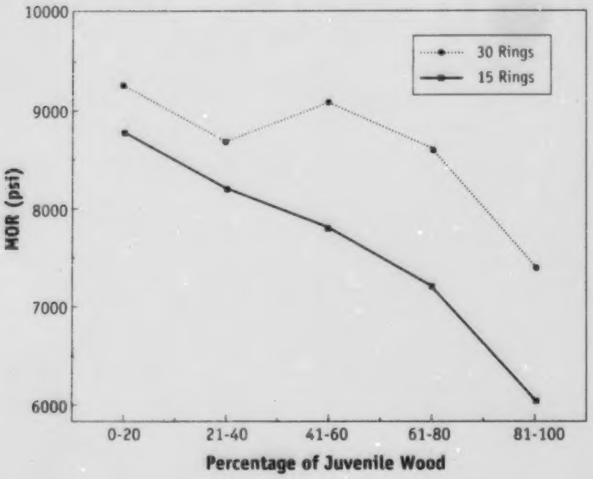


Figure 3-20

Mean MOR for 105x105 mm Select Structural Squares Related to Juvenile Wood Class



Results of the regression analysis are provided below:

Mean MOE ($\times 10^6$ psi) = -0.354 +5.21(BH DENS) – 0.00486 (DBH)

	Partial R^2		
BH DENS	.55		
DBH	.02	**Total**	.57

Mean MOR (psi) = -1100 + 24900(BH DENS) – 38.4(DBH)

	Partial R^2		
BH DENS	.38		
DBH	.04	**Total**	.42

Various measures of knot size (knot indices) were added to the above equations. Mean knot size replaced d.b.h. as the second most significant variable in both the MOE and MOR equations. R^2 for MOE increased slightly to .59, and R^2 for MOR increased to .44. These slight improvements in prediction would not warrant obtaining knot or branch measurements.

MOE and MOR of 105x105 mm Squares and 45x105 mm Side Lumber Compared by Stand

Engineering properties were compared on the basis of squares and side lumber to provide further insight into stand-to-stand differences in the properties of juvenile wood (squares) versus mature wood (side lumber). Table 3-8 shows stand-to-stand ratios of mean MOR and MOE of 105x105 mm squares and 45x105 mm lumber for all grades combined, and for Select Structural grade alone.

As expected, the smallest stand-to-stand differences were between the two 930 sph stands with values from PR930 ranging from two to nine percent higher than those from PH930. The differences were greatest between PR930 and PH580 where, for example, MOR for all grades of 105x105 mm squares from PR930 was 30 percent higher than MOR from PH580.

Stand-to-stand differences were generally lower for 45x105 mm lumber compared to the 105x105 mm squares. This indicates that structural wood properties varied less in the

Table 3-8 *Stand-to-Stand Ratios of Mean MOR and MOE by Dimension and Visual Grade*

Dimension (mm)	Test Property Mean	PR930/PH580		PH930/PH580		PR930/PH930	
		All Grades	Select Structural	All Grades	Select Structural	All Grades	Select Structural
		Ratio					
105x105	MOR	1.30	1.24	1.23	1.18	1.06	1.04
	MOE	1.26	1.24	1.16	1.14	1.09	1.09
45x105	MOR	1.20	1.20	1.16	1.13	1.04	1.06
	MOE	1.15	1.15	1.13	1.13	1.02	1.02

outer mature wood zone than nearer the pith where varying proportions of juvenile wood exert influence. It also suggests that difference in knot size between stands was not a major contributor to differences in MOE and MOR in outside lumber.

Stand-to-stand differences were consistently larger for the combined grades of 105x105 mm squares than for the Select Structural grade. This confirms that visual grading served to segregate some of the quality differences between stands.

Table 3-9 *Visual Grade Distributions for 105x105 mm Squares and 45x105 mm Lumber by Stand*

Dimension (mm)	Visual Grade	Stand		
		PH580	PH930	PR930
		Percent by Volume		
105x105	Select Structural	50.6	78.3	69.9
	No. 1	26.6	7.0	9.5
	No. 2	15.6	10.8	14.6
	No. 3	4.6	1.9	6.0
	Economy	0.4	0.0	0.0
	Reject	2.3	1.9	0.0
45x105	Select Structural	26.2	48.5	47.8
	No. 1	33.7	22.2	18.5
	No. 2	24.2	17.3	18.1
	No. 3	10.2	4.7	12.2
	Economy	3.5	4.7	0.9
	Reject	2.2	2.5	2.5

Visual grade distributions for 105x105 squares and 45x105 lumber by stand are shown in Table 3-9. Compared to the 105x105 mm squares, the 45x105 mm side lumber contained significantly lower percentages of Select Structural grade in all three stands which reflects the effect that knots have on visual grades. The PH580 stand produced the lowest percentage of Select Structural from both sizes.

The mean MOE and MOR values obtained for the selected size and grade breakdowns by stand are shown in Table 3-10. Within the Select Structural grade, mean MOE and MOR values for all three stands were significantly higher for 45x105 mm side lumber (mature wood) than for the 105x105 mm squares. Within the No.2 grade, mean MOR for all three stands is lower for the 45x105 mm lumber than for the 105x105 mm squares. This indicates that in lower grades the visual grade determining factors (knots, knot type, localized slope-of-grain, etc.) out weighed the positive effect of higher wood density associated with mature wood.

5 Conclusions

In drawing conclusions from this study it is important to note that the results of the engineering tests that have been described do not apply to western hemlock in general, nor do they invalidate the visual grades that were assigned. Material similar to the samples tested here would be found in the total population of hemlock lumber to which the design values for grades apply. Design values would be affected only if this material became a large proportion of the total hem-fir lumber population.

Table 3-10 *Mean MOE and Mean MOR for 105x105 mm Squares and 45x105 mm Lumber by Visual Grade and Stand*

Size (mm)	NLGA Grade	Stand								
		PH580			PH930			PR930		
		N	MOR (psi)	MOE ($\times10^6$ psi)	N	MOR (psi)	MOE ($\times10^6$ psi)	N	MOR (psi)	MOE $\times10^6$ psi
105x105	SS	648	7393	1.579	240	8759	1.798	193	9130	1.963
	No. 1	340	6435	1.487	21	8188	1.731	24	8051	1.772
	No. 2	200	6764	1.565	34	7754	1.744	41	9644	2.055
	No. 3	58	6149	1.418	4	5435	1.639	16	7636	1.798
	Econ	5	4151	1.118	-	-	-	-	-	-
	Reject	17	6373	1.507	5	6977	1.626	-	-	
	All	1268	6954	1.542	304	8534	1.738	274	9025	1.950
45x105	SS	84	7800	1.727	59	8833	1.945	53	9393	1.987
	No. 1	110	6889	1.630	25	7439	1.810	21	7375	1.845
	No. 2	78	6368	1.606	19	6841	1.705	19	7843	1.850
	No. 3	27	6427	1.536	3	5390	1.590	9	6521	1.593
	Econ	10	6177	1.599	4	7280	1.650	1	4505	1.728
	Reject	4	6060	1.705	1	6082	1.660	2	4241	1.650
	All	313	6931	1.642	111	8004	1.851	105	8318	1.891

Figure 3-19
Mean MOE for 105x105 mm Select Structural Squares Related to Juvenile Wood Class

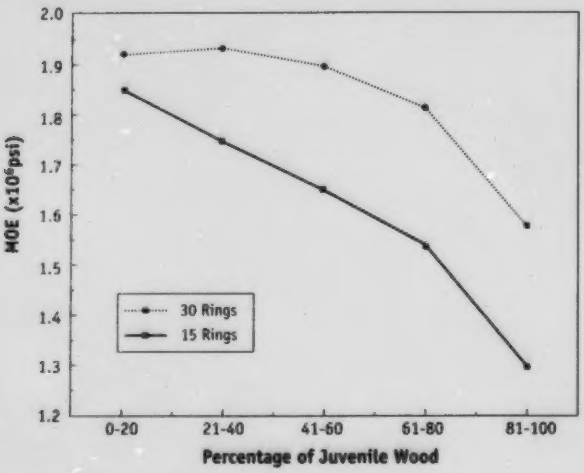
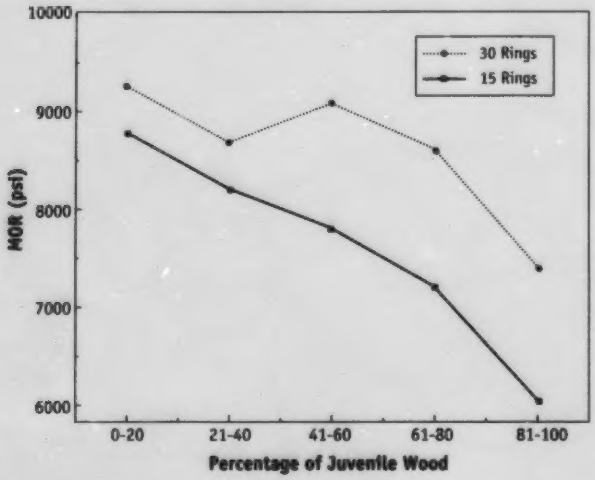


Figure 3-20
Mean MOR for 105x105 mm Select Structural Squares Related to Juvenile Wood Class



Results of the regression analysis are provided below:

Mean MOE ($x10^6$ psi) = -0.354 +5.21(BH DENS) – 0.00486 (DBH)

	Partial R^2		
BH DENS	.55		
DBH	.02	**Total**	.57

Mean MOR (psi) = -1100 + 24900(BH DENS) – 38.4(DBH)

	Partial R^2		
BH DENS	.38		
DBH	.04	**Total**	.42

Various measures of knot size (knot indices) were added to the above equations. Mean knot size replaced d.b.h. as the second most significant variable in both the MOE and MOR equations. R^2 for MOE increased slightly to .59, and R^2 for MOR increased to .44. These slight improvements in prediction would not warrant obtaining knot or branch measurements.

MOE and MOR of 105x105 mm Squares and 45x105 mm Side Lumber Compared by Stand

Engineering properties were compared on the basis of squares and side lumber to provide further insight into stand-to-stand differences in the properties of juvenile wood (squares) versus mature wood (side lumber). Table 3-8 shows stand-to-stand ratios of mean MOR and MOE of 105x105 mm squares and 45x105 mm lumber for all grades combined, and for Select Structural grade alone.

As expected, the smallest stand-to-stand differences were between the two 930 sph stands with values from PR930 ranging from two to nine percent higher than those from PH930. The differences were greatest between PR930 and PH580 where, for example, MOR for all grades of 105x105 mm squares from PR930 was 30 percent higher than MOR from PH580.

Stand-to-stand differences were generally lower for 45x105 mm lumber compared to the 105x105 mm squares. This indicates that structural wood properties varied less in the

Table 3-8 *Stand-to-Stand Ratios of Mean MOR and MOE by Dimension and Visual Grade*

Dimension (mm)	Test Property Mean	PR930/PH580		PH930/PH580		PR930/PH930	
		All Grades	Select Structural	All Grades	Select Structural	All Grades	Select Structural
		Ratio					
105x105	MOR	1.30	1.24	1.23	1.18	1.06	1.04
	MOE	1.26	1.24	1.16	1.14	1.09	1.09
45x105	MOR	1.20	1.20	1.16	1.13	1.04	1.06
	MOE	1.15	1.15	1.13	1.13	1.02	1.02

outer mature wood zone than nearer the pith where varying proportions of juvenile wood exert influence. It also suggests that difference in knot size between stands was not a major contributor to differences in MOE and MOR in outside lumber.

Stand-to-stand differences were consistently larger for the combined grades of 105x105 mm squares than for the Select Structural grade. This confirms that visual grading served to segregate some of the quality differences between stands.

Table 3-9 *Visual Grade Distributions for 105x105 mm Squares and 45x105 mm Lumber by Stand*

Dimension (mm)	Visual Grade	Stand		
		PH580	PH930	PR930
		Percent by Volume		
105x105	Select Structural	50.6	78.3	69.9
	No. 1	26.6	7.0	9.5
	No. 2	15.6	10.8	14.6
	No. 3	4.6	1.9	6.0
	Economy	0.4	0.0	0.0
	Reject	2.3	1.9	0.0
45x105	Select Structural	26.2	48.5	47.8
	No. 1	33.7	22.2	18.5
	No. 2	24.2	17.3	18.1
	No. 3	10.2	4.7	12.2
	Economy	3.5	4.7	0.9
	Reject	2.2	2.5	2.5

Visual grade distributions for 105x105 squares and 45x105 lumber by stand are shown in Table 3-9. Compared to the 105x105 mm squares, the 45x105 mm side lumber contained significantly lower percentages of Select Structural grade in all three stands which reflects the effect that knots have on visual grades. The PH580 stand produced the lowest percentage of Select Structural from both sizes.

The mean MOE and MOR values obtained for the selected size and grade breakdowns by stand are shown in Table 3-10. Within the Select Structural grade, mean MOE and MOR values for all three stands were significantly higher for 45x105 mm side lumber (mature wood) than for the 105x105 mm squares. Within the No.2 grade, mean MOR for all three stands is lower for the 45x105 mm lumber than for the 105x105 mm squares. This indicates that in lower grades the visual grade determining factors (knots, knot type, localized slope-of-grain, etc.) out weighed the positive effect of higher wood density associated with mature wood.

5 Conclusions

In drawing conclusions from this study it is important to note that the results of the engineering tests that have been described do not apply to western hemlock in general, nor do they invalidate the visual grades that were assigned. Material similar to the samples tested here would be found in the total population of hemlock lumber to which the design values for grades apply. Design values would be affected only if this material became a large proportion of the total hem-fir lumber population.

Table 3-10 *Mean MOE and Mean MOR for 105x105 mm Squares and 45x105 mm Lumber by Visual Grade and Stand*

Size (mm)	NLGA Grade	Stand								
		PH580			PH930			PR930		
		N	MOR (psi)	MOE ($\times10^6$ psi)	N	MOR (psi)	MOE ($\times10^6$ psi)	N	MOR (psi)	MOE $\times10^6$ psi
105x105	SS	648	7393	1.579	240	8759	1.798	193	9130	1.963
	No. 1	340	6435	1.487	21	8188	1.731	24	8051	1.772
	No. 2	200	6764	1.565	34	7754	1.744	41	9644	2.055
	No. 3	58	6149	1.418	4	5435	1.639	16	7636	1.798
	Econ	5	4151	1.118	-	-	-	-	-	-
	Reject	17	6373	1.507	5	6977	1.626	-	-	
	All	1268	6954	1.542	304	8534	1.738	274	9025	1.950
45x105	SS	84	7800	1.727	59	8833	1.945	53	9393	1.987
	No. 1	110	6889	1.630	25	7439	1.810	21	7375	1.845
	No. 2	78	6368	1.606	19	6841	1.705	19	7843	1.850
	No. 3	27	6427	1.536	3	5390	1.590	9	6521	1.593
	Econ	10	6177	1.599	4	7280	1.650	1	4505	1.728
	Reject	4	6060	1.705	1	6082	1.660	2	4241	1.650
	All	313	6931	1.642	111	8004	1.851	105	8318	1.891

Differences in the wood characteristics of trees obtained from the three stands evaluated in this study resulted in some significant differences in MOE and MOR values. Trends in MOE and MOR were consistent with trends in wood density. Based on comparisons of the most prevalent lumber dimension, 105x105 mm squares, average MOE and MOR values were highest for the PR930 stand, followed by the PH930 stand, and were lowest for the PH580 stand. MOE and MOR values for 45x105 mm side-cut lumber were not significantly different for the two 930 sph stands, but were significantly lower for lumber from the PH580 sph stand.

Lumber MOR and MOE values were significantly related to proportions of juvenile wood defined as wood within 15 years of the pith. Although within-stand MOE and MOR were inconsistently related to tree size, tree growth rates to 15 years differed by stand and were inversely related to differences in average MOE and MOR. Segregating lumber into discrete classes by juvenile wood proportions resulted in significantly different mean MOE and MOR values.

Considered by position in the tree, MOE and MOR values were generally highest in butt logs, trended down over the first 12 to 16 m up the tree, and then increased. PH580 was the exception with MOE for first, second and third log positions being below that in logs higher in the tree. Wood density values followed a similar trend. Lumber properties from logs in crown positions were not evaluated because small logs were not converted to lumber.

Considered by tree d.b.h. class, mean MOE values for 105x105 mm Select Structural squares from both 930 sph stands equalled or significantly exceeded the design value for Hem-Fir (Canadian Standard 086.1-94). However, the mean MOE values for 105x105 mm Select Structural lumber for d.b.h. classes 40 cm and larger in the PH580 sph stand fell significantly below the Select Structural design value. Mean MOE from the largest d.b.h. class was not significantly different from a No.3 design value.

Second-growth western hemlock grown at slow-to-moderate rates for the first 15 years, equivalent to that of the PR930 stand, can be expected to produce lumber with structural values that are equivalent to those of old growth. Trees grown at faster rates will have lower structural properties.

Results obtained from this study indicate that second-growth western hemlock lumber will continue to meet design standards for Hem-Fir even when lumber from more open stands becomes part of the general mix. The lumber volume from trees in open grown stands will be a very small proportion of total lumber volume. Higher than average MOE values obtained from the more generally prevalent densely grown stands, and from smaller d.b.h. classes not included in this study, will more than compensate. However, lumber from relatively open grown second-growth western hemlock will not have structural properties equivalent to those of old growth and the implications for stand value should be considered in stand density management decisions.

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Appendix

MOE and MOR Statistics Summarized for NLGA Structural Grades

MOE[1] (x 10^6 psi) For All D.b.h. Classes Combined

Grade	Size	PH 580				PH 930				PR 930			
		n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]
SS	105 x 105	648	1.579	0.276	1.559 - 1.599	240	1.798	0.239	1.766 - 1.830	193	1.963	0.229	1.926 - 1.999
	90 x 90	45	1.846	0.285	1.771 - 1.922	39	2.028	0.261	1.947 - 2.110	23	2.068	0.248	1.963 - 2.174
	36 x 90	48	1.720	0.251	1.647 - 1.793	26	1.949	0.187	1.850 - 2.049	19	1.920	0.224	1.803 - 2.036
	36 x 105	56	1.697	0.209	1.629 - 1.765	20	1.854	0.125	1.740 - 1.967	19	1.793	0.212	1.676 - 1.909
	36 x 140	197	1.724	0.202	1.688 - 1.760	69	1.886	0.173	1.825 - 1.947	72	1.890	0.226	1.830 - 1.950
	36 x 190	70	1.630	0.225	1.570 - 1.691	10	1.851	0.200	1.691 - 2.011	7	1.808	0.253	1.616 - 1.999
	45 x 90	31	1.773	0.221	1.682 - 1.864	18	1.945	0.282	1.826 - 2.065	7	1.949	0.251	1.758 - 2.141
	45 x 105	84	1.727	0.278	1.671 - 1.782	59	1.945	0.261	1.879 - 2.011	53	1.987	0.283	1.917 - 2.056
	45 x 140	29	1.607	0.224	1.513 - 1.701	7	1.591	0.262	1.400 - 1.783	5	1.943	0.304	1.716 - 2.170
	45 x 190	21	1.528	0.138	1.418 - 1.639	11	1.747	0.153	1.594 - 1.900	8	1.754	0.231	1.575 - 1.933
No.1	105 x 105	340	1.487	0.249	1.459 - 1.514	21	1.731	0.202	1.620 - 1.841	24	1.772	0.242	1.669 - 1.876
	90 x 90	21	1.642	0.284	1.531 - 1.752	5	1.809	0.140	1.582 - 2.036	4	2.120	0.178	1.867 - 2.374
	36 x 90	18	1.636	0.241	1.516 - 1.755	8	1.849	0.153	1.670 - 2.028	6	1.585	0.226	1.378 - 1.791
	36 x 105	23	1.633	0.215	1.527 - 1.738	2	1.462	0.114	1.103 - 1.820	3	1.637	0.014	1.344 - 1.930
	36 x 140	38	1.513	0.340	1.431 - 1.595	2	1.777	0.398	1.418 - 2.135	8	1.702	0.306	1.523 - 1.881
	36 x 190	7	1.492	0.219	1.301 - 1.684	1	1.364		0.857 - 1.871				
	45 x 90	23	1.700	0.319	1.595 - 1.806	4	2.090	0.183	1.836 - 2.343	7	1.747	0.255	1.556 - 1.938
	45 x 105	110	1.630	0.214	1.582 - 1.678	25	1.810	0.196	1.709 - 1.911	21	1.845	0.223	1.735 - 1.956
	45 x 140	5	1.634	0.193	1.408 - 1.861					2	1.442	0.157	1.084 - 1.800
	45 x 190	3	1.618	0.082	1.325 - 1.910	1	1.294		0.787 - 1.801				
No.2	105 x 105	200	1.565	0.288	1.530 - 1.601	34	1.744	0.227	1.657 - 1.831	41	2.055	0.289	1.975 - 2.134
	90 x 90	23	1.850	0.265	1.744 - 1.956	7	1.984	0.394	1.793 - 2.176	6	2.202	0.238	1.995 - 2.409
	36 x 90	27	1.646	0.227	1.548 - 1.743	7	1.745	0.374	1.554 - 1.937	15	1.829	0.293	1.699 - 1.960
	36 x 105	31	1.580	0.215	1.489 - 1.671	11	1.691	0.245	1.538 - 1.843	12	1.531	0.454	1.385 - 1.677
	36 x 140	37	1.579	0.213	1.495 - 1.662	10	1.853	0.280	1.693 - 2.013	9	1.809	0.220	1.641 - 1.978
	36 x 190	15	1.509	0.231	1.378 - 1.640	1	1.895		1.388 - 2.402	3	2.024	0.157	1.731 - 2.317
	45 x 90	32	1.651	0.285	1.562 - 1.741	3	1.785	0.428	1.493 - 2.078				
	45 x 105	78	1.606	0.251	1.548 - 1.663	19	1.705	0.206	1.589 - 1.821	19	1.850	0.279	1.734 - 1.966
	45 x 140	6	1.647	0.293	1.440 - 1.853	4	1.859	0.108	1.606 - 2.113				
	45 x 190	8	1.577	0.173	1.397 - 1.756	2	1.719	0.274	1.360 - 2.077				
No.3	105 x 105	58	1.418	0.348	1.351 - 1.484	4	1.639	0.267	1.386 - 1.893	16	1.798	0.266	1.671 - 1.924
	90 x 90	11	1.951	0.327	1.798 - 2.103					4	2.035	0.313	1.781 - 2.288
	36 x 90	8	1.576	0.279	1.397 - 1.755	2	2.098	0.049	1.740 - 2.456	5	1.654	0.206	1.427 - 1.880
	36 x 105	17	1.582	0.241	1.459 - 1.705	3	1.734	0.411	1.441 - 2.026	3	1.718	0.398	1.426 - 2.011
	36 x 140	14	1.637	0.287	1.502 - 1.773	1	1.729		1.222 - 2.236	10	1.701	0.321	1.541 - 1.861
	36 x 190	8	1.668	0.282	1.489 - 1.847	3	1.742	0.107	1.449 - 2.034				
	45 x 90	10	1.637	0.144	1.477 - 1.798	2	1.973	0.160	1.615 - 2.331	4	1.653	0.473	1.399 - 1.906
	45 x 105	27	1.536	0.299	1.438 - 1.633	3	1.590	0.388	1.297 - 1.883	9	1.593	0.254	1.424 - 1.762
	45 x 140	4	1.503	0.106	1.249 - 1.756					1	2.031		1.524 - 2.538
	45 x 190	1	1.445		0.938 - 1.952					2	1.263	0.078	0.905 - 1.621

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[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.258 and t = 1.96*

MOE[1] (x 10^6 psi) For 30 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]
SS	105 x 105	9	1.601	0.214	1.437 - 1.765	12	1.762	0.194	1.620 - 1.904	8	1.928	0.134	1.754 - 2.102
	90 x 90	6	1.692	0.309	1.490 - 1.893	5	1.930	0.190	1.709 - 2.150	3	1.932	0.172	1.647 - 2.216
	36 x 90	7	1.724	0.368	1.538 - 1.910	4	1.791	0.111	1.544 - 2.037	2	1.769	0.273	1.420 - 2.118
	36 x 105	4	1.417	0.147	1.170 - 1.663	6	1.918	0.149	1.717 - 2.119	3	1.685	0.228	1.400 - 1.970
	36 x 140	1	1.928		1.435 - 2.421	3	1.881	0.283	1.596 - 2.166	1	1.879		1.386 - 2.372
	45 x 90	4	1.795	0.201	1.549 - 2.042	1	1.777		1.284 - 2.270	3	1.806	0.356	1.521 - 2.090
	45 x 105	7	1.565	0.230	1.379 - 1.752	4	1.774	0.147	1.527 - 2.020	7	1.894	0.329	1.708 - 2.081
	45 x 140	2	1.554	0.300	1.205 - 1.903	1	1.678		1.185 - 2.171	1	1.405		0.912 - 1.898
	45 x 190					1	1.503		1.010 - 1.996	2	1.678	0.294	1.329 - 2.027
No.1	105 x 105	1	1.477		0.984 - 1.969					1	1.428		0.935 - 1.921
	36 x 140									1	1.427		0.934 - 1.920
	45 x 90	1	1.805		1.312 - 2.298								
	45 x 105	1	1.690		1.197 - 2.183								
No.2	105 x 105	1	1.484		0.991 - 1.977	2	2.007	0.235	1.658 - 2.355	2	1.981	0.477	1.633 - 2.330
	90 x 90	2	2.056	0.028	1.708 - 2.405	1	2.181		1.689 - 2.674	1	2.448		1.955 - 2.941
	36 x 90	1	1.582		1.089 - 2.075	1	2.123		1.630 - 2.616	1	1.654		1.161 - 2.147
	36 x 140									1	1.294		0.801 - 1.787
	45 x 90					1	1.472		0.979 - 1.965				
	45 x 105	1	1.372		0.879 - 1.865	2	1.475	0.150	1.126 - 1.824				
	45 x 140					1	1.762		1.269 - 2.255				
No.3	90 x 90									1	2.179		1.686 - 2.672
	36 x 90									1	1.938		1.445 - 2.431
	36 x 105					1	2.107		1.614 - 2.600				
	36 x 140	1	1.585		1.092 - 2.078								
	45 x 105	1	1.701		1.208 - 2.194					1	1.457		0.964 - 1.950

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[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.251 and t = 1.96*

MOE[1] (x 10^6 psi) For 35 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]
SS	105 x 105	33	1.681	0.247	1.595 - 1.767	42	1.909	0.240	1.832 - 1.985	23	2.053	0.306	1.950 - 2.156
	90 x 90	5	1.827	0.211	1.607 - 2.048	11	2.163	0.223	2.014 - 2.312	2	1.974	0.166	1.626 - 2.323
	36 x 90	8	1.622	0.149	1.448 - 1.796	7	1.929	0.188	1.743 - 2.115	5	2.133	0.267	1.912 - 2.353
	36 x 105	4	1.905	0.107	1.659 - 2.151	6	1.774	0.067	1.572 - 1.975	1	1.640		1.147 - 2.133
	36 x 140	9	1.760	0.238	1.595 - 1.924	13	1.935	0.210	1.798 - 2.072	12	1.919	0.180	1.776 - 2.061
	36 x 190	1	1.750		1.257 - 2.243								
	45 x 90	7	1.819	0.223	1.633 - 2.006	8	1.888	0.325	1.713 - 2.062	1	2.077		1.584 - 2.570
	45 x 105	9	1.682	0.184	1.517 - 1.846	22	1.943	0.248	1.838 - 2.048	15	2.157	0.281	2.030 - 2.284
	45 x 140	1	1.499		1.006 - 1.992	2	1.673	0.083	1.324 - 2.022				
	45 x 190	2	1.368	0.213	1.019 - 1.716	1	1.854		1.361 - 2.347	1	2.196		1.703 - 2.689
No.1	105 x 105	3	1.615	0.079	1.331 - 1.900	1	1.645		1.153 - 2.138	3	1.983	0.224	1.698 - 2.267
	90 x 90	1	1.213		0.721 - 1.706								
	36 x 90					1	1.682		1.189 - 2.175				
	36 x 105	3	1.642	0.280	1.357 - 1.927								
	36 x 140	2	1.808	0.047	1.459 - 2.157					1	1.669		1.176 - 2.162
	45 x 90	1	1.525		1.032 - 2.018	2	2.040	0.118	1.691 - 2.388				
	45 x 105	7	1.568	0.256	1.382 - 1.754	3	1.880	0.171	1.595 - 2.164	3	1.977	0.282	1.692 - 2.262
No.2	105 x 105	6	1.643	0.329	1.442 - 1.845	3	1.890	0.240	1.606 - 2.175	9	2.076	0.212	1.912 - 2.241
	90 x 90	2	2.004	0.057	1.655 - 2.352	3	1.961	0.485	1.676 - 2.245	1	1.946		1.453 - 2.439
	36 x 90									3	2.033	0.048	1.748 - 2.317
	36 x 105	2	1.680	0.291	1.331 - 2.028	1	1.776		1.283 - 2.269	2	0.953	1.022	0.604 - 1.301
	36 x 140	1	1.426		0.933 - 1.919	1	2.215		1.722 - 2.708	1	1.997		1.504 - 2.490
	36 x 190									1	2.115		1.622 - 2.608
	45 x 90	4	1.726	0.518	1.479 - 1.972	1	2.273		1.780 - 2.766				
	45 x 105	4	1.635	0.417	1.388 - 1.881	1	2.003		1.510 - 2.496	4	1.923	0.227	1.676 - 2.169
	45 x 140					1	1.857		1.364 - 2.350				
No.3	105 x 105									6	1.698	0.256	1.496 - 1.899
	90 x 90									3	1.986	0.364	1.702 - 2.271
	36 x 90	1	1.877		1.384 - 2.370								
	36 x 105	1	1.385		0.892 - 1.878					1	1.859		1.366 - 2.352
	36 x 140	3	1.558	0.283	1.273 - 1.843					5	1.645	0.343	1.425 - 1.866
	45 x 90									1	1.874		1.381 - 2.367
	45 x 105	1	1.347		0.854 - 1.840					2	1.628	0.258	1.279 - 1.976
	45 x 190									2	1.263	0.078	0.914 - 1.612

[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.251 and t = 1.96*

MOE[1] (x 10^6 psi) For 40 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]
SS	105 x 105	97	1.625	0.205	1.575 - 1.675	76	1.814	0.202	1.757 - 1.871	62	1.958	0.209	1.895 - 2.020
	90 x 90	11	1.908	0.159	1.759 - 2.056	12	2.000	0.271	1.857 - 2.142	7	2.082	0.228	1.896 - 2.269
	36 x 90	4	1.683	0.195	1.436 - 1.929	8	1.944	0.234	1.769 - 2.118	8	1.894	0.127	1.720 - 2.068
	36 x 105	10	1.650	0.177	1.494 - 1.806	4	1.812	0.143	1.566 - 2.058	10	1.737	0.189	1.581 - 1.893
	36 x 140	38	1.736	0.166	1.656 - 1.816	22	1.844	0.170	1.739 - 1.949	19	1.899	0.200	1.786 - 2.012
	36 x 190	3	1.338	0.314	1.053 - 1.623	1	1.661		1.168 - 2.154	2	1.957	0.227	1.608 - 2.305
	45 x 90	5	1.572	0.151	1.352 - 1.793	4	2.006	0.083	1.760 - 2.252	1	2.030		1.537 - 2.523
	45 x 105	13	1.603	0.176	1.466 - 1.740	18	1.934	0.239	1.818 - 2.050	12	1.922	0.151	1.780 - 2.064
	45 x 140	5	1.539	0.124	1.318 - 1.759	3	1.394	0.276	1.110 - 1.679	1	2.058		1.565 - 2.551
	45 x 190	2	1.481	0.172	1.132 - 1.829	2	1.865	0.156	1.516 - 2.213	3	1.757	0.129	1.472 - 2.042
No.1	105 x 105	6	1.727	0.086	1.526 - 1.929	7	1.742	0.124	1.555 - 1.928	4	1.724	0.166	1.477 - 1.970
	90 x 90					2	1.933	0.131	1.585 - 2.282	2	2.089	0.020	1.741 - 2.438
	36 x 90	2	1.744	0.132	1.395 - 2.093	1	1.851		1.358 - 2.344	4	1.640	0.239	1.394 - 1.886
	36 x 105	2	1.433	0.134	1.084 - 1.782	2	1.462	0.114	1.113 - 1.810	2	1.645	0.008	1.296 - 1.993
	36 x 140	1	1.590		1.097 - 2.083	1	1.495		1.002 - 1.988	2	1.633	0.636	1.284 - 1.982
	36 x 190					1	1.364		0.871 - 1.857				
	45 x 90	2	1.811	0.207	1.462 - 2.159					4	1.764	0.280	1.517 - 2.010
	45 x 105	15	1.653	0.223	1.525 - 1.780	8	1.685	0.113	1.511 - 1.859	7	1.685	0.215	1.499 - 1.872
	45 x 140									1	1.331		0.838 - 1.824
	45 x 190					1	1.294		0.801 - 1.787				
No.2	105 x 105	12	1.723	0.184	1.580 - 1.865	16	1.733	0.223	1.610 - 1.856	16	1.939	0.362	1.816 - 2.063
	90 x 90	2	1.877	0.098	1.529 - 2.226								
	36 x 90	3	1.821	0.226	1.537 - 2.106	2	1.841	0.277	1.492 - 2.190	3	1.697	0.271	1.413 - 1.982
	36 x 105	2	1.664	0.023	1.315 - 2.013	5	1.723	0.197	1.503 - 1.944	4	1.595	0.241	1.349 - 1.842
	36 x 140	4	1.799	0.136	1.553 - 2.046	4	1.774	0.209	1.527 - 2.020	3	1.773	0.042	1.489 - 2.058
	45 x 90	4	1.797	0.233	1.550 - 2.043								
	45 x 105	8	1.745	0.242	1.570 - 1.919	7	1.726	0.237	1.540 - 1.912	4	1.622	0.121	1.376 - 1.868
	45 x 140					1	1.808		1.315 - 2.301				
No.3	105 x 105	5	1.681	0.123	1.461 - 1.902	4	1.639	0.267	1.393 - 1.886	7	1.829	0.258	1.642 - 2.015
	36 x 90	1	1.710		1.217 - 2.203					1	1.657		1.164 - 2.150
	36 x 105	1	1.630		1.137 - 2.123	2	1.547	0.359	1.198 - 1.896	1	1.269		0.776 - 1.762
	36 x 140	1	1.855		1.362 - 2.348	1	1.729		1.236 - 2.222	3	1.652	0.376	1.368 - 1.937
	36 x 190	3	1.686	0.261	1.401 - 1.970	1	1.742		1.249 - 2.235				
	45 x 90									1	1.467		0.974 - 1.960
	45 x 105	1	1.784		1.291 - 2.277	1	1.660		1.167 - 2.153	3	1.823	0.230	1.539 - 2.108

[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.251 and t = 1.96*

MOE[1] (x 10^6 psi) For 45 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]	n	mean	s	95% C.I.[2]
SS	105 x 105	124	1.664	0.230	1.620 - 1.708	110	1.749	0.253	1.702 - 1.796	100	1.948	0.224	1.898 - 1.997
	90 x 90	4	1.624	0.202	1.378 - 1.870	11	1.970	0.291	1.821 - 2.119	11	2.113	0.293	1.965 - 2.262
	36 x 90	11	1.709	0.205	1.561 - 1.858	7	2.067	0.083	1.881 - 2.254	4	1.780	0.161	1.533 - 2.026
	36 x 105	7	1.845	0.176	1.659 - 2.031	4	1.918	0.067	1.672 - 2.164	5	1.998	0.142	1.778 - 2.219
	36 x 140	45	1.726	0.158	1.652 - 1.799	31	1.896	0.150	1.808 - 1.985	40	1.877	0.254	1.799 - 1.955
	36 x 190	10	1.726	0.074	1.570 - 1.882	9	1.872	0.200	1.708 - 2.036	5	1.748	0.260	1.528 - 1.969
	45 x 90	3	1.939	0.290	1.654 - 2.223	5	2.022	0.353	1.801 - 2.242	2	2.061	0.127	1.712 - 2.410
	45 x 105	10	1.810	0.209	1.654 - 1.965	15	2.006	0.322	1.879 - 2.133	19	1.927	0.294	1.814 - 2.040
	45 x 140	4	1.818	0.120	1.571 - 2.064	1	1.931	.	1.438 - 2.424	3	2.084	0.060	1.799 - 2.369
	45 x 190	2	1.607	0.062	1.258 - 1.956	7	1.733	0.135	1.547 - 1.919	2	1.606	0.035	1.257 - 1.954
No.1	105 x 105	22	1.612	0.250	1.507 - 1.717	13	1.732	0.245	1.595 - 1.868	16	1.767	0.246	1.643 - 1.890
	90 x 90	3	1.849	0.178	1.565 - 2.134	3	1.726	0.070	1.442 - 2.011	2	2.151	0.302	1.803 - 2.500
	36 x 90	2	1.680	0.100	1.331 - 2.029	6	1.876	0.162	1.675 - 2.077	2	1.474	0.216	1.125 - 1.823
	36 x 105	4	1.650	0.231	1.403 - 1.896					1	1.622		1.129 - 2.115
	36 x 140	5	1.620	0.214	1.399 - 1.840	1	2.058		1.565 - 2.551	4	1.813	0.195	1.567 - 2.059
	45 x 90	4	1.784	0.109	1.538 - 2.031	2	2.140	0.276	1.791 - 2.489	3	1.725	0.274	1.440 - 2.009
	45 x 105	17	1.693	0.211	1.574 - 1.813	14	1.866	0.212	1.735 - 1.998	11	1.911	0.166	1.763 - 2.060
	45 x 140	1	1.781		1.288 - 2.274					1	1.553		1.060 - 2.046
	45 x 190	1	1.711		1.218 - 2.204								
No.2	105 x 105	21	1.706	0.225	1.599 - 1.814	13	1.683	0.211	1.546 - 1.820	14	2.182	0.160	2.051 - 2.314
	90 x 90					3	1.942	0.455	1.658 - 2.227	4	2.204	0.230	1.958 - 2.451
	36 x 90	8	1.725	0.185	1.550 - 1.899	4	1.603	0.417	1.357 - 1.849	8	1.825	0.346	1.650 - 1.999
	36 x 105	8	1.693	0.105	1.519 - 1.867	5	1.641	0.323	1.420 - 1.861	6	1.681	0.212	1.480 - 1.882
	36 x 140	4	1.648	0.148	1.402 - 1.895	5	1.844	0.324	1.623 - 2.064	4	1.919	0.099	1.672 - 2.165
	36 x 190	5	1.687	0.124	1.466 - 1.907	1	1.895		1.402 - 2.388	2	1.979	0.192	1.630 - 2.327
	45 x 90	3	1.449	0.156	1.164 - 1.733	1	1.611		1.118 - 2.104				
	45 x 105	10	1.669	0.212	1.513 - 1.825	9	1.707	0.161	1.543 - 1.871	11	1.907	0.306	1.758 - 2.055
	45 x 140	1	1.659		1.166 - 2.152	1	2.010		1.517 - 2.503				
	45 x 190	1	1.853		1.360 - 2.346	2	1.719	0.274	1.370 - 2.067				
No.3	105 x 105	7	1.613	0.215	1.427 - 1.800					3	1.925	0.333	1.640 - 2.209
	36 x 90					2	2.098	0.049	1.749 - 2.447	3	1.558	0.174	1.273 - 1.842
	36 x 105	2	1.828	0.145	1.479 - 2.176					1	2.027		1.534 - 2.520
	36 x 140	3	1.643	0.130	1.358 - 1.927					2	1.913	0.256	1.564 - 2.262
	36 x 190					2	1.742	0.151	1.393 - 2.090				
	45 x 90	1	1.859		1.366 - 2.352	2	1.973	0.160	1.624 - 2.322	2	1.635	0.767	1.286 - 1.984
	45 x 105	1	1.605		1.112 - 2.098	2	1.555	0.542	1.206 - 1.904	3	1.385	0.133	1.100 - 1.669
	45 x 140									1	2.031		1.538 - 2.524

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[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.251 and t = 1.96*

MOE[1] (x 10^6 psi) For 50 cm D.b.h. Class

Grade	Size	PH 580			
		n	mean	s	95% C.I.[2]
SS	105 x 105	135	1.601	0.284	1.558 - 1.643
	90 x 90	8	1.693	0.308	1.519 - 1.867
	36 x 90	7	1.632	0.308	1.446 - 1.818
	36 x 105	15	1.690	0.112	1.562 - 1.817
	36 x 140	37	1.769	0.185	1.688 - 1.850
	36 x 190	10	1.647	0.251	1.491 - 1.803
	45 x 90	4	1.833	0.196	1.587 - 2.080
	45 x 105	16	1.712	0.314	1.589 - 1.835
	45 x 140	5	1.684	0.289	1.463 - 1.904
	45 x 190	6	1.571	0.107	1.369 - 1.772
No.1	105 x 105	47	1.584	0.238	1.513 - 1.656
	90 x 90	8	1.509	0.227	1.335 - 1.684
	36 x 90	5	1.602	0.200	1.382 - 1.823
	36 x 105	2	1.460	0.305	1.111 - 1.808
	36 x 140	5	1.710	0.257	1.489 - 1.930
	36 x 190	1	1.667		1.174 - 2.160
	45 x 90	3	1.928	0.439	1.643 - 2.213
	45 x 105	25	1.621	0.225	1.523 - 1.720
	45 x 140	2	1.563	0.091	1.214 - 1.911
No.2	105 x 105	37	1.620	0.291	1.539 - 1.702
	90 x 90	4	1.632	0.190	1.385 - 1.878
	36 x 90	6	1.606	0.211	1.404 - 1.807
	36 x 105	5	1.576	0.112	1.356 - 1.796
	36 x 140	10	1.603	0.256	1.447 - 1.759
	36 x 190	2	1.555	0.211	1.206 - 1.904
	45 x 90	8	1.679	0.336	1.505 - 1.854
	45 x 105	15	1.638	0.234	1.511 - 1.766
	45 x 140	2	1.969	0.041	1.620 - 2.318
	45 x 190	1	1.274		0.781 - 1.767
No.3	105 x 105	8	1.192	0.323	1.018 - 1.366
	90 x 90	5	2.028	0.338	1.808 - 2.249
	36 x 90	3	1.699	0.107	1.415 - 1.984
	36 x 105	3	1.734	0.093	1.450 - 2.019
	36 x 140	2	1.729	0.666	1.380 - 2.078
	36 x 190	1	1.939		1.446 - 2.432
	45 x 90	4	1.635	0.153	1.389 - 1.882
	45 x 105	5	1.547	0.147	1.326 - 1.767
	45 x 140	2	1.506	0.084	1.157 - 1.854

[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.251 and t = 1.96*

MOE[1] (x 10^6 psi) For 55 cm D.b.h. Class

Grade	Size	PH 580			
		n	mean	s	95% C.I.[2]
SS	105 x 105	123	1.556	0.259	1.512 - 1.601
	90 x 90	6	2.087	0.267	1.885 - 2.288
	36 x 90	7	1.971	0.123	1.784 - 2.157
	36 x 105	6	1.781	0.312	1.579 - 1.982
	36 x 140	40	1.730	0.218	1.652 - 1.808
	36 x 190	25	1.685	0.230	1.587 - 1.784
	45 x 90	5	1.695	0.172	1.475 - 1.916
	45 x 105	19	1.884	0.325	1.771 - 1.997
	45 x 140	5	1.593	0.259	1.372 - 1.813
	45 x 190	5	1.505	0.091	1.284 - 1.725
No.1	105 x 105	86	1.574	0.241	1.520 - 1.627
	90 x 90	4	1.893	0.215	1.647 - 2.140
	36 x 90	3	1.758	0.338	1.473 - 2.043
	36 x 105	6	1.754	0.149	1.552 - 1.955
	36 x 140	10	1.592	0.279	1.436 - 1.748
	36 x 190	2	1.687	0.261	1.338 - 2.035
	45 x 90	8	1.482	0.351	1.308 - 1.656
	45 x 105	24	1.681	0.191	1.580 - 1.782
	45 x 140	1	1.867		1.374 - 2.360
	45 x 190	2	1.571	0.021	1.222 - 1.920
No.2	105 x 105	51	1.631	0.284	1.562 - 1.700
	90 x 90	8	2.008	0.195	1.834 - 2.182
	36 x 90	3	1.827	0.250	1.542 - 2.112
	36 x 105	8	1.475	0.268	1.301 - 1.650
	36 x 140	8	1.563	0.233	1.389 - 1.737
	36 x 190	3	1.509	0.158	1.224 - 1.794
	45 x 90	4	1.637	0.181	1.390 - 1.883
	45 x 105	19	1.616	0.222	1.503 - 1.729
	45 x 140	1	1.649		1.156 - 2.142
	45 x 190	2	1.522	0.031	1.173 - 1.871
No.3	105 x 105	9	1.602	0.309	1.437 - 1.766
	90 x 90	2	1.919	0.248	1.571 - 2.268
	36 x 105	4	1.608	0.077	1.361 - 1.854
	36 x 140	1	2.113		1.620 - 2.606
	36 x 190	1	1.995		1.502 - 2.488
	45 x 90	2	1.677	0.147	1.328 - 2.026
	45 x 105	4	1.463	0.602	1.217 - 1.710

[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.251 and t = 1.96*

MOE[1] (x 10^6 psi) for 60 cm D.b.h. Class

Grade	Size	PH 580			
		n	mean	s	95% C.I.[2]
SS	105 x 105	127	1.434	0.324	1.390 - 1.477
	90 x 90	5	2.049	0.321	1.829 - 2.270
	36 x 90	4	1.688	0.275	1.442 - 1.934
	36 x 105	10	1.630	0.217	1.474 - 1.786
	36 x 140	27	1.617	0.271	1.522 - 1.712
	36 x 190	21	1.548	0.202	1.441 - 1.656
	45 x 90	3	1.849	0.305	1.564 - 2.134
	45 x 105	10	1.681	0.283	1.525 - 1.837
	45 x 140	7	1.522	0.226	1.335 - 1.708
	45 x 190	4	1.559	0.203	1.312 - 1.805
No.1	105 x 105	175	1.392	0.224	1.355 - 1.429
	90 x 90	5	1.613	0.291	1.393 - 1.833
	36 x 90	6	1.551	0.299	1.350 - 1.753
	36 x 105	6	1.621	0.222	1.419 - 1.822
	36 x 140	15	1.314	0.382	1.187 - 1.442
	36 x 190	4	1.352	0.107	1.105 - 1.598
	45 x 90	4	1.844	0.259	1.598 - 2.091
	45 x 105	21	1.533	0.194	1.425 - 1.640
	45 x 140	1	1.399		0.906 - 1.892
No.2	105 x 105	72	1.418	0.261	1.360 - 1.476
	90 x 90	5	1.617	0.303	1.397 - 1.838
	36 x 90	6	1.412	0.113	1.211 - 1.614
	36 x 105	6	1.510	0.290	1.308 - 1.711
	36 x 140	10	1.466	0.136	1.310 - 1.621
	36 x 190	5	1.313	0.244	1.092 - 1.533
	45 x 90	9	1.602	0.213	1.438 - 1.767
	45 x 105	21	1.495	0.258	1.388 - 1.603
	45 x 140	2	1.317	0.037	0.968 - 1.666
	45 x 190	4	1.610	0.101	1.364 - 1.857
No.3	105 x 105	29	1.331	0.354	1.239 - 1.422
	90 x 90	4	1.869	0.406	1.623 - 2.116
	36 x 90	3	1.308	0.276	1.024 - 1.593
	36 x 105	6	1.432	0.316	1.231 - 1.633
	36 x 140	3	1.436	0.034	1.151 - 1.720
	36 x 190	3	1.451	0.220	1.166 - 1.735
	45 x 90	3	1.540	0.082	1.255 - 1.825
	45 x 105	14	1.532	0.276	1.400 - 1.664
	45 x 140	2	1.500	0.163	1.151 - 1.849
	45 x 190	1	1.445		0.952 - 1.938

[1] *In static bending adjusted to 15% MC*

[2] *95% confidence interval based on Anova RMSE = 0.251 and t = 1.96*

MOR[1] (psi) For All D.b.h. Classes Combined

Grade	Size	PH 580				PH 930				PR 930			
		n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	648	4440	4109 - 4744	95	240	6252	5627 - 6554	96	193	6356	5793 - 6725	95
	90 x 90	45	4896	4356 - 6347	88	39	7112	5972 - 8097	85	23	7772	7763 - 8725	69
	36 x 90	48	4598	3673 - 5923	91	26	6042	5283 - 7919	73	19	6950	6950 - 8428	61
	36 x 105	56	5197	3647 - 5466	92	20	6317	6307 - 7266	63	19	5512	5512 - 6393	61
	36 x 140	197	4075	3255 - 4224	95	69	5039	4697 - 6002	95	72	5170	4005 - 5857	97
	36 x 190	70	3576	2688 - 4032	95	10	6197	6197 - 7040	39	7	4926	4926 - 6990	30
	45 x 90	31	4852	4760 - 6067	78	18	6972	6972 - 7588	59	7	6995	6995 - 8913	30
	45 x 105	84	4561	3171 - 5195	96	59	5224	2335 - 6794	94	53	5153	4110 - 6287	92
	45 x 140	29	4650	4578 - 5696	76	7	2560	2560 - 6577	30	5	7811		
	45 x 190	21	3822	3767 - 4973	64	11	3109	3109 - 5266	42	8	4625	4625 - 5265	33
No.1	105 x 105	340	3872	3465 - 4161	95	21	6142	6081 - 6777	64	24	5095	4851 - 6825	70
	90 x 90	21	3279	3231 - 4905	64	5	5582			4	8056		
	36 x 90	18	4357	4357 - 5865	59	8	7667	7667 - 8936	33	6	4427		
	36 x 105	23	4696	4663 - 5597	69	2	4622			3	5287		
	36 x 140	38	2359	1494 - 3703	85	2	4306			8	3583	3583 - 5642	33
	36 x 190	7	3343	3343 - 4898	30	1	1412						
	45 x 90	23	2789	2671 - 5513	69	4	7939			7	5361	5361 - 7512	30
	45 x 105	110	3402	2644 - 4557	95	25	4691	4632 - 5969	72	21	3392	3240 - 5975	64
	45 x 140	5	3891							2	5440		
	45 x 190	3	2620			1	2174						
No.2	105 x 105	200	3938	3508 - 4491	97	34	3139	3012 - 5737	82	41	6150	5140 - 7300	86
	90 x 90	23	3902	3748 - 6518	69	7	4821	4821 - 7948	30	6	6461		
	36 x 90	27	4807	4587 - 5980	74	7	5046	5046 - 7389	30	15	3730	3730 - 6968	53
	36 x 105	31	3186	3153 - 5503	78	11	3473	3473 - 5833	42	12	878	878 - 6742	44
	36 x 140	37	3069	2534 - 3405	84	10	5361	5361 - 6108	39	9	4689	4689 - 6828	36
	36 x 190	15	1426	1426 - 3441	53	1	8345			3	7248		
	45 x 90	32	4263	3994 - 4942	79	3	6466						
	45 x 105	78	3042	2549 - 4007	97	19	2894	2894 - 5012	61	19	5002	5002 - 5583	61
	45 x 140	6	4221			4	7741						
	45 x 190	8	4194	4194 - 5434	33	2	3027						
No.3	105 x 105	58	2078	1027 - 3913	94	4	2905			16	4060	4060 - 4984	55
	90 x 90	11	4872	4872 - 8323	42					4	5333		
	36 x 90	8	3157	3157 - 6350	33	2	8719			5	4544		
	36 x 105	17	3531	3531 - 4933	57	3	1488			3	4311		
	36 x 140	14	2982	2982 - 4038	51	1	9890			10	1955	1955 - 3509	39
	36 x 190	8	4360	4360 - 5869	33	3	5978						
	45 x 90	10	3666	3666 - 5386	39	2	8533			4	3143		
	45 x 105	27	2763	2313 - 4658	74	3	1980			9	4417	4417 - 5016	36
	45 x 140	4	6009							1	10511		
	45 x 190	1	6160							2	2284		

---

[1] *In static bending adjusted to 15% MC*

[2] *5th percentile non-parametric point estimate*

[3] *Confidence interval for the 5th percentile*

[4] *Confidence (%) associated with the above confidence interval*

MOR[1] (psi) For 30 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	9	5421	5421 - 7705	36	12	5822	5822 - 6248	44	8	6578	6578 - 8486	33
	90 x 90	6	4809			5	7112			3	7763		
	36 x 90	7	7331	7331 - 8953	30	4	7511			2	8845		
	36 x 105	4	5603			6	7087			3	6320		
	36 x 140	1	9444			3	6504			1	9415		
	45 x 90	4	7515			1	11202			3	6995		
	45 x 105	7	3333	3333 - 6157	30	4	5536			7	5000	5000 - 8364	30
	45 x 140	2	7047			1	6577			1	9969		
	45 x 190					1	5681			2	6993		
No.1	105 x 105	1	6097							1	4851		
	36 x 140									1	4815		
	45 x 90	1	8722										
	45 x 105	1	9466										
No.2	105 x 105	1	8432			2	9968			2	6248		
	90 x 90	2	9179			1	10867			1	14133		
	36 x 90	1	10433			1	8524			1	7782		
	36 x 140									1	4689		
	45 x 90					1	6466						
	45 x 105	1	8906			2	2894						
	45 x 140					1	8234						
No.3	90 x 90									1	12002		
	36 x 90									1	7617		
	36 x 105					1	7751						
	36 x 140	1	6238										
	45 x 105	1	8858							1	6827		

---

[1] In static bending adjusted to 15% MC
[2] 5th percentile non-parametric point estimate
[3] Confidence interval for the 5th percentile
[4] Confidence (%) associated with the above confidence interval

MOR[1] (psi) For 35 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	33	4248	3792 - 6527	79	42	6807	6422 - 7744	87	23	6164	5822 - 8704	69
	90 x 90	5	6599			11	7673	7673 - 9277	42	2	11223		
	36 x 90	8	6745	6745 - 7489	33	7	7452	7452 - 8166	30	5	8535		
	36 x 105	4	8054			6	6498			1	9757		
	36 x 140	9	3945	3945 - 6877	36	13	4937	4937 - 6092	46	12	4005	4005 - 5518	44
	36 x 190	1	4593										
	45 x 90	7	7653	7653 - 7920	30	8	7529	7529 - 8081	33	1	8032		
	45 x 105	9	4660	4660 - 6580	36	22	5437	5224 - 7690	65	15	5536	5536 - 8719	53
	45 x 140	1	6596			2	7148						
	45 x 190	2	5467			1	9779			1	9403		
No.1	105 x 105	3	6641			1	8510			3	8001		
	90 x 90	1	3823										
	36 x 90					1	9340						
	36 x 105	3	5684										
	36 x 140	2	5810							1	7103		
	45 x 90	1	5258			2	9047						
	45 x 105	7	2512	2512 - 4581	30	3	6696			3	6796		
No.2	105 x 105	6	3756			3	7918			9	6139	6139 - 8457	36
	90 x 90	2	7854			3	5380			1	7714		
	36 x 90									3	8236		
	36 x 105	2	7572			1	6859			2	878		
	36 x 140	1	2534			1	9724			1	10081		
	36 x 190									1	8989		
	45 x 90	4	4881			1	10479						
	45 x 105	4	3007			1	9119			4	5024		
	45 x 140					1	8464						
No.3	105 x 105									6	4338		
	90 x 90									3	5333		
	36 x 90	1	10148										
	36 x 105	1	5130							1	9183		
	36 x 140	3	4779							5	3509		
	45 x 90									1	8352		
	45 x 105	1	8050							2	4489		
	45 x 190									2	2284		

[1] *In static bending adjusted to 15% MC*
[2] *5th percentile non-parametric point estimate*
[3] *Confidence interval for the 5th percentile*
[4] *Confidence (%) associated with the above confidence interval*

MOR[1] (psi) For 40 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	97	4835	4027 - 5534	97	76	5975	3843 - 6581	97	62	6379	5793 - 6845	95
	90 x 90	11	6411	6411 - 6504	42	12	5972	5972 - 8097	44	7	8240	8240 - 8981	30
	36 x 90	4	3673			8	5283	5283 - 9990	33	8	8385	8385 - 8820	33
	36 x 105	10	3647	3647 - 5330	39	4	6307			10	5840	5840 - 7822	39
	36 x 140	38	3853	3141 - 4489	85	22	4876	4697 - 6031	65	19	5375	5375 - 6899	61
	36 x 190	3	2688			1	10118			2	6990		
	45 x 90	5	4760			4	7926			1	9726		
	45 x 105	13	3171	3171 - 5196	46	18	2335	2335 - 6937	59	12	6082	6082 - 8593	44
	45 x 140	5	4908			3	2560			1	8846		
	45 x 190	2	4973			2	5266			3	4625		
No.1	105 x 105	6	6281			7	6722	6722 - 7227	30	4	6270		
	90 x 90					2	5582			2	8056		
	36 x 90	2	7256			1	8936			4	5240		
	36 x 105	2	4663			2	4622			2	5287		
	36 x 140	1	5980			1	4306			2	3583		
	36 x 190					1	1412						
	45 x 90	2	7360							4	5361		
	45 x 105	15	2644	2644 - 5889	53	8	6274	6274 - 6340	33	7	3240	3240 - 5975	30
	45 x 140									1	6025		
	45 x 190					1	2174						
No.2	105 x 105	12	5413	5413 - 5797	44	16	3012	3012 - 6064	55	16	5140	5140 - 7300	55
	90 x 90	2	6112										
	36 x 90	3	8430			2	5118			3	6968		
	36 x 105	2	5825			5	3473			4	3401		
	36 x 140	4	5140			4	6108			3	8122		
	45 x 90	4	5516										
	45 x 105	8	4176	4176 - 6034	33	7	5012	5012 - 5918	30	4	5583		
	45 x 140					1	7741						
No.3	105 x 105	5	4624			4	2905			7	4060	4060 - 7267	30
	36 x 90	1	10002							1	4544		
	36 x 105	1	9607			2	1488			1	4311		
	36 x 140	1	8947			1	9890			3	1955		
	36 x 190	3	5869			1	5978						
	45 x 90									1	3562		
	45 x 105	1	4835			1	3210			3	6505		

---

[1] *In static bending adjusted to 15% MC*

[2] *5th percentile non-parametric point estimate*

[3] *Confidence interval for the 5th percentile*

[4] *Confidence (%) associated with the above confidence interval*

MOR[1] (psi) For 45 cm D.b.h. Class

Grade	Size	PH 580				PH 930				PR 930			
		n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]	n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	124	4792	3890 - 5606	97	110	6255	4459 - 6633	95	100	6059	5130 - 7014	95
	90 x 90	4	6347			11	7136	7136 - 9126	42	11	7809	7809 - 9631	42
	36 x 90	11	5923	5923 - 7029	42	7	9321	9321 - 9790	30	4	6950		
	36 x 105	7	5695	5695 - 7673	30	4	7377			5	5512		
	36 x 140	45	4132	3484 - 4490	88	31	5464	5077 - 6225	78	40	4846	4171 - 5965	86
	36 x 190	10	3946	3946 - 5521	39	9	6197	6197 - 7040	36	5	4926		
	45 x 90	3	7450			5	6972			2	8913		
	45 x 105	10	5405	5405 - 7719	39	15	6457	6457 - 7955	53	19	4110	4110 - 6805	61
	45 x 140	4	6182			1	9309			3	7811		
	45 x 190	2	5766			7	3109	3109 - 5505	30	2	5265		
No.1	105 x 105	22	4301	4191 - 5303	65	13	6081	6081 - 6874	46	16	5828	5828 - 6841	55
	90 x 90	3	6146			3	8034			2	9101		
	36 x 90	2	6670			6	7667			2	4427		
	36 x 105	4	5287							1	8010		
	36 x 140	5	3775			1	9350			4	5642		
	45 x 90	4	6901			2	7939			3	6444		
	45 x 105	17	4156	4156 - 5052	57	14	4632	4632 - 5427	51	11	4758	4758 - 6617	42
	45 x 140	1	6725							1	5440		
	45 x 190	1	6595										
No.2	105 x 105	21	4836	4671 - 6484	64	13	4368	4368 - 5408	46	14	7910	7910 - 8921	51
	90 x 90					3	4821			4	6461		
	36 x 90	8	5137	5137 - 6334	33	4	5046			8	3730	3730 - 6466	33
	36 x 105	8	6550	6550 - 7041	33	5	5833			6	9220		
	36 x 140	4	4626			5	5361			4	5069		
	36 x 190	5	3509			1	8345			2	7248		
	45 x 90	3	4589			1	8058						
	45 x 105	10	4047	4047 - 6078	39	9	3894	3894 - 6433	36	11	5002	5002 - 6274	42
	45 x 140	1	5424			1	10927						
	45 x 190	1	5434			2	3027						
No.3	105 x 105	7	6069	6069 - 7149	30					3	7228		
	36 x 90					2	8719			3	5524		
	36 x 105	2	4933							1	8854		
	36 x 140	3	3431							2	7932		
	36 x 190					2	6820						
	45 x 90	1	8731			2	8533			2	3143		
	45 x 105	1	7073			2	1980			3	4417		
	45 x 140									1	10511		

---

[1] *In static bending adjusted to 15% MC*

[2] *5th percentile non-parametric point estimate*

[3] *Confidence interval for the 5th percentile*

[4] *Confidence (%) associated with the above confidence interval*

MOR[1] (psi) For 50 cm D.b.h. Class

Grade	Size	PH 580			
		n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	135	3535	2757 - 4613	95
	90 x 90	8	4356	4356 - 5669	33
	36 x 90	7	4356	4356 - 6830	30
	36 x 105	15	5293	5293 - 6395	53
	36 x 140	37	4569	2629 - 5757	84
	36 x 190	10	4032	4032 - 5828	39
	45 x 90	4	4914		
	45 x 105	16	4553	4553 - 7409	55
	45 x 140	5	4578		
	45 x 190	6	4316		
No.1	105 x 105	47	3916	3726 - 5565	90
	90 x 90	8	3231	3231 - 5739	33
	36 x 90	5	5197		
	36 x 105	2	4974		
	36 x 140	5	3660		
	36 x 190	1	7286		
	45 x 90	3	6839		
	45 x 105	25	3952	3951 - 5268	72
	45 x 140	2	7118		
No.2	105 x 105	37	3499	3416 - 4587	84
	90 x 90	4	5207		
	36 x 90	6	5596		
	36 x 105	5	5781		
	36 x 140	10	4248	4248 - 5442	39
	36 x 190	2	3556		
	45 x 90	8	3994	3994 - 5255	33
	45 x 105	15	3044	3044 - 4535	53
	45 x 140	2	9782		
	45 x 190	1	5627		
No.3	105 x 105	8	2109	2109 - 2737	33
	90 x 90	5	8323		
	36 x 90	3	7371		
	36 x 105	3	6279		
	36 x 140	2	2982		
	36 x 190	1	7818		
	45 x 90	4	3666		
	45 x 105	5	5196		
	45 x 140	2	6009		

[1] *In static bending adjusted to 15% MC*
[2] *5th percentile non-parametric point estimate*
[3] *Confidence interval for the 5th percentile*
[4] *Confidence (%) associated with the above confidence interval*

MOR[1] (psi) For 55 cm D.b.h. Class

Grade	Size	PH 580			
		n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	123	5021	3214 - 5455	97
	90 x 90	6	7147		
	36 x 90	7	8566	8566 - 10432	30
	36 x 105	6	5572		
	36 x 140	40	4119	3255 - 5154	86
	36 x 190	25	3382	3224 - 5361	72
	45 x 90	5	7842		
	45 x 105	19	4660	4660 - 7033	61
	45 x 140	5	6821		
	45 x 190	5	5789		
No.1	105 x 105	86	3721	2638 - 4551	96
	90 x 90	4	7872		
	36 x 90	3	7734		
	36 x 105	6	4829		
	36 x 140	10	2945	2945 - 5491	39
	36 x 190	2	4898		
	45 x 90	8	2671	2671 - 3461	33
	45 x 105	24	4725	4658 - 6131	70
	45 x 140	1	8399		
	45 x 190	2	2620		
No.2	105 x 105	51	4434	4109 - 5358	91
	90 x 90	8	6518	6518 - 7174	33
	36 x 90	3	7919		
	36 x 105	8	3153	3153 - 4900	33
	36 x 140	8	3128	3128 - 4917	33
	36 x 190	3	2843		
	45 x 90	4	5136		
	45 x 105	19	2598	2598 - 4486	61
	45 x 140	1	4431		
	45 x 190	2	4194		
No.3	105 x 105	9	4641	4641 - 5204	36
	90 x 90	2	9363		
	36 x 105	4	4034		
	36 x 140	1	9403		
	36 x 190	1	8585		
	45 x 90	2	6611		
	45 x 105	4	2313		

[1] *In static bending adjusted to 15% MC*
[2] *5th percentile non-parametric point estimate*
[3] *Confidence interval for the 5th percentile*
[4] *Confidence (%) associated with the above confidence interval*

MOR[1] (psi) For 60 cm D.b.h. Class

Grade	Size	PH 580			
		n	5th %ile[2]	C.I.[3]	%[4]
SS	105 x 105	127	4052	3762 - 4493	96
	90 x 90	5	7797		
	36 x 90	4	5082		
	36 x 105	10	5239	5239 - 6149	39
	36 x 140	27	3499	3200 - 4642	74
	36 x 190	21	3416	3364 - 4374	64
	45 x 90	3	7543		
	45 x 105	10	4584	4584 - 6384	39
	45 x 140	7	4721	4721 - 6241	30
	45 x 190	4	3767		
No.1	105 x 105	175	3555	3152 - 4043	96
	90 x 90	5	4905		
	36 x 90	6	4357		
	36 x 105	6	5597		
	36 x 140	15	1494	1494 - 3703	53
	36 x 190	4	3343		
	45 x 90	4	5847		
	45 x 105	21	3264	3250 - 4557	64
	45 x 140	1	3891		
No.2	105 x 105	2	3658	3294 - 4271	97
	90 x 90	5	3748		
	36 x 90	6	4587		
	36 x 105	6	5164		
	36 x 140	10	3128	3128 - 3405	39
	36 x 190	5	1426		
	45 x 90	9	4408	4408 - 6089	36
	45 x 105	21	2663	2549 - 4078	64
	45 x 140	2	4221		
	45 x 190	4	5689		
No.3	105 x 105	29	1258	1027 - 3968	76
	90 x 90	4	4872		
	36 x 90	3	3157		
	36 x 105	6	3531		
	36 x 140	3	3636		
	36 x 190	3	4360		
	45 x 90	3	4499		
	45 x 105	14	3437	3437 - 4658	51
	45 x 140	2	6557		
	45 x 190	1	6160		

[1] *In static bending adjusted to 15% MC*

[2] *5th percentile non-parametric point estimate*

[3] *Confidence interval for the 5th percentile*

[4] *Confidence (%) associated with the above confidence interval*

SECTION

4

MECHANICAL PROPERTIES OF SMALL CLEARS

G.R. Middleton, B.D. Munro and C. Lum

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SECTION

4

MECHANICAL PROPERTIES OF SMALL CLEARS

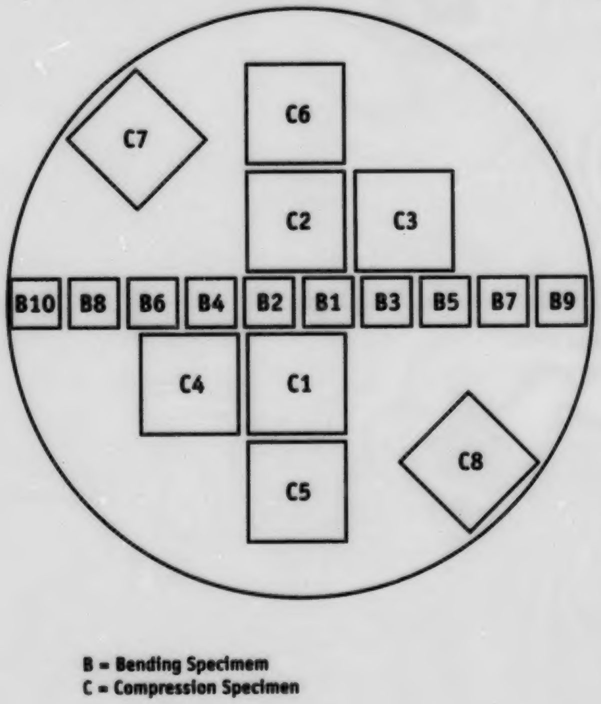
1 Introduction

This study augments results obtained from an earlier study of the mechanical properties of small clear specimens of BC coastal second-growth western hemlock (Ellis, 1998). Tests of small, straight-grained specimens free of defects were the traditional method of determining mechanical properties of wood. These have given way to tests of full-sized lumber, but remain useful because they provide a basis for making comparisons with published data not otherwise readily available.

Kennedy and Swann (1969) published results from testing small clear specimens obtained from 102 western hemlock boards sampled in equal number from 11 sawmills operating in the BC western hemlock growing regions. Reported average estimates for modulus of rupture (MOR) and modulus of elasticity (MOE) were 7030 psi and 1540 (10^3) psi. They noted that western hemlock was similar to Douglas-fir in that it was exceptionally strong and stiff for its weight. They related MOE and MOR to average tree specific gravity obtained from breast-height increment cores for 602 western hemlock trees sampled in the same regions. They reported that growth rate was the single factor most closely associated with specific gravity variation.

Jessome (1986) reported mechanical properties of western hemlock obtained from testing small clear specimens.

Figure 4-1
Cutting Plan for Small Clears



2 Objective

To determine, and compare by stand of origin, the mechanical properties of small clear specimens of second-growth coastal BC western hemlock.

3 Methods

Three trees, one small, one medium and one large diameter, were selected from each of three stands on Vancouver Island previously described: PH580, PH930, and PR930. Numbers in the designations represent current stand densities. Bolts of wood approximately 1 m in length were cut from close to breast height, and from 40 percent of tree height from each of the 9 trees.

Figure 1 shows the cutting plan for obtaining clear specimens from the bolts. The orientation of the cross-section was selected at random and then adjusted to avoid knots and compression wood. Bending and compression specimens were labeled "B" and "C" respectively. Actual numbers of specimens obtained depended on the bolt diameter, and the presence of any unseen defects.

Properties were assessed in accordance with ASTM D143 procedures: modulus of rupture (or bending strength) bending modulus of elasticity, compression parallel-to-grain strength and compression modulus of elasticity.

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4 Results and Discussion

Bending Tests

Table 4-1 provides bending MOE and MOR statistics for small clear specimens obtained from each of the three sample locations. Analysis of variance showed stand effects to be highly significant (0.001 level).

Predictability was low. With MOE as the response variable $R^2 = 0.18$, and for MOR versus stand $R^2 = .37$. Tested at the 0.05 level, mean MOE and MOR for PH930 and PR930 were not significantly different, but mean values from both of these two stands were significantly different from those of the more open PH580 stand.

Figure 4-2 is a box plot comparison of MOE means and distributions by stand. Figure 4-3 provides a similar comparison for MOR.

Table 4-1 *Bending Properties of Small Clears*

		Stand		
		PH580	**PH930**	**PR 930**
MOR (psi)	n	52	34	30
	mean	10340	12931	13598
	s	1628	2469	2480
	min	7445	7125	9590
	max	13782	18773	17709
MOE (10^6 psi)	n	52	34	30
	mean	1.489	1.822	1.864
	s	0.269	0.481	0.432
	min	1.019	0.824	1.179
	max	2.111	2.751	2.817

Figure 4-2
Bending MOE Compared by Stand

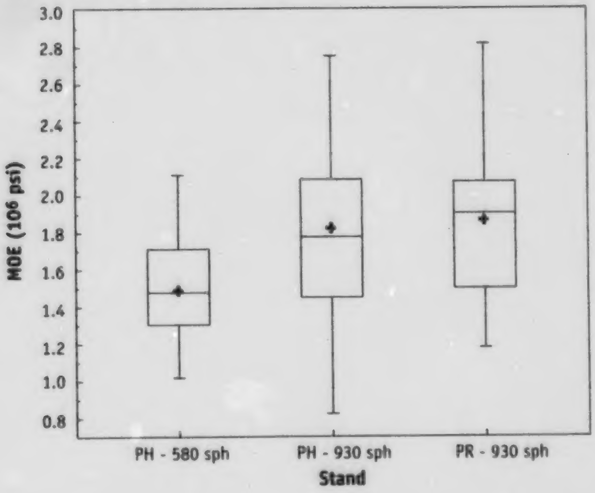
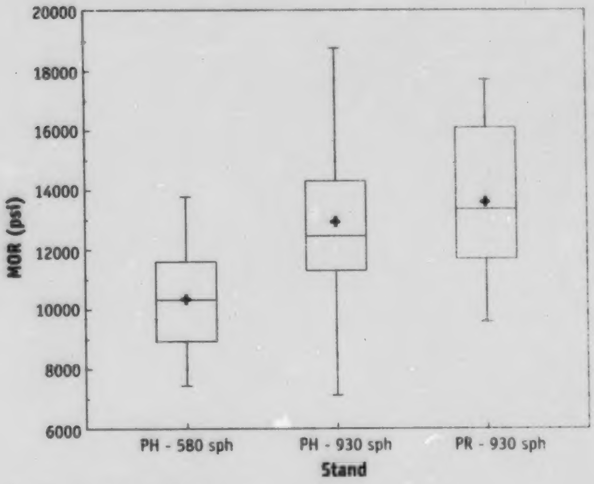


Figure 4-3
Bending MOR Compared by Stand



Compression Tests

Table 4-2 provides statistics for MOE and ultimate compression strength (UCS) in compression for second-growth western hemlock by stand of origin. The mean values for MOE and UCS show the same trends by stand as were evident in the bending results. Mean wood density values show identical trends.

Figure 4-4 shows MOE in compression compared by stand. Analysis of variance for MOE by stand showed again that stand of origin was significant (0.001 level) and that predictability was low ($R^2 = .23$). Mean MOE was not signifi-

Table 4-2 *Compression Properties of Small Clears*

		Stand		
		PH580	**PH930**	**PR930**
UCS (psi)	n	49	31	25
	mean	5628	6828	7132
	s	554	1082	761
	min	4190	5170	5790
	max	6560	8970	8430
MOE (10^6 psi)	n	49	31	25
	mean	1.680	1.999	2.192
	s	0.357	0.485	0.351
	min	0.925	1.234	1.618
	max	2.517	3.010	3.104
Wood Density	n	49	31	25
	mean	0.445	0.505	0.531
	s	0.039	0.074	0.054
	min	0.362	0.403	0.421
	max	0.522	0.638	0.630

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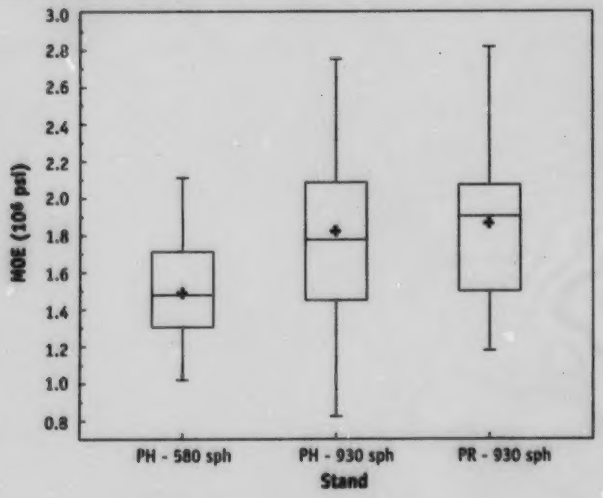
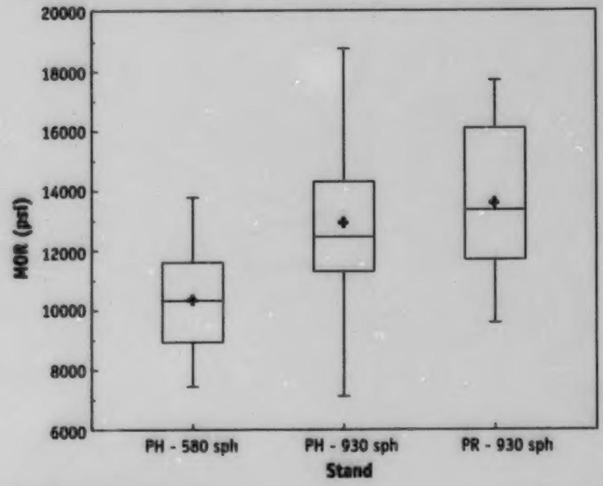


Figure 4-3
Bending MOR Compared by Stand



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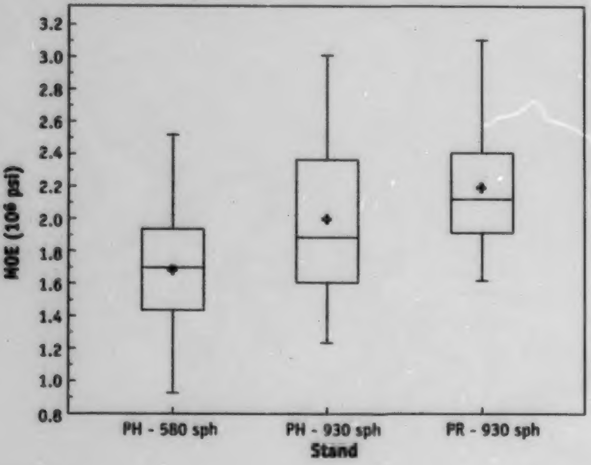
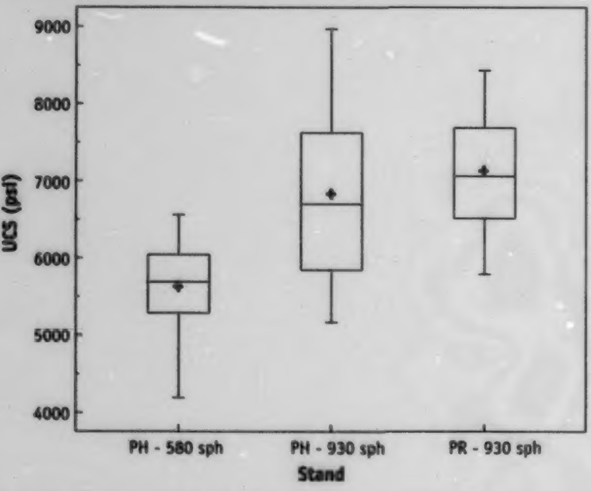


Figure 4-5
Ultimate Compression Strength Compared by Stand



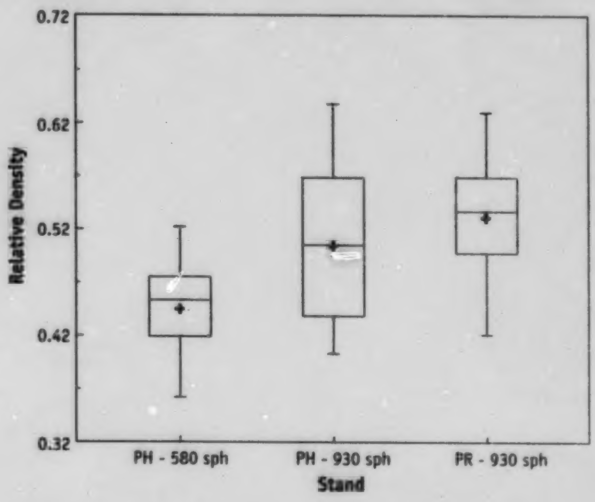
cantly different (0.05 level) between the PH930 and PR930 stands, but mean MOE for PH580 was significantly lower compared to that of both other stands.

Figure 4-5 shows UCS compared by stand. Analysis of variance of UCS by stand produced the same levels of significance for the response variables, and the same grouping of stands in terms of significant differences. Predictability of UCS was also somewhat higher (R^2= .43).

Wood Density

Stand statistics for wood density[1] of small clears were included in Table 4-2. Stand effects were significant at the 0.001 level. Analysis of variance of wood density by stand (R^2 = .33) produced a similar pattern of results as obtained for stand effects on mechanical properties in bending and compression. Wood density means and distributions by stand are shown in Figure 4-6.

Figure 4-6
Wood Density Compared by Stand



Influence of Growth Rate

Wood density and strength and stiffness properties of small clears increased from PH580 to PH930 and to PR930. This is the inverse of early growth rates observed for the stands as previously described. An inverse relationship between wood mechanical properties and growth rate is consistent with results obtained by Kennedy and Swann, 1969.

Comparison with Published Values for Western Hemlock

Jessome (1986) reported western hemlock[2] species mean MOE and MOR in static bending as 1.784 x10^6 psi, and 11,762 psi respectively. Mean MOE and mean UCS in compression parallel to grain were reported to be 1.755 x 10^6 psi and 6,773 psi respectively. All published properties exceeded those obtained for wood from PH580. Published properties were lower than those for wood from PH930 and PR930.

5 Conclusions

The mechanical properties of small clear wood specimens obtained from the two more dense stands were not significantly different, but were significantly higher than those from the more open stand.

---

[1] Wood density here was calculated on an oven-dry weight and oven dry volume basis.

[2] For air dry western hemlock adjusted to 12% moisture content.

Differences in properties between stands were consistent with, and inversely related to differences in growth rate. Properties for the open stand (PH580) fell below published values, those of the two more dense stands (PH930 and PR930) exceeded published values.

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Jozsa, L., B.D. Munro and J.R. Gordon. 1998. Basic wood properties of second-growth western hemlock. Spec. Pub. SP-38. B.C. Ministry of Forests, Victoria, BC

Jessome A.P. 1986. Strength and related properties of woods grown in Canada. Fish. Env. Can., Eastern For. Prod. Lab, Ottawa, ON. For. Tech. Rep. 21.

Kennedy, R.W. and G.W. Swann. 1969. Comparative specific gravity and strength of amabilis fir and western hemlock in British Columbia. Dept. Fish. Can. For. Prod. Lab., Vancouver, B.C. Inf. Rep. VP-X-50.

SECTION

5

VENEER AND LVL PROPERTIES

Chunping Dai, Feng Fu and Brad Wang

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VENEE[illegible] [illegible] PROPE[illegible]

5

1 Introduction

This work was focused on the veneer characteristics of second-growth western hemlock from coastal British Columbia. Veneer is an essential constituent of wood composite products such as plywood, laminated veneer lumber (LVL) and parallel-strand lumber (Parallam). All these products are produced in British Columbia, and veneer-based products are still the largest composite sector in the province. Traditionally the main veneer species have been spruce, pine, subalpine fir (SPF) and Douglas fir. Extending the fibre source to include other species would benefit the veneer-based industry.

Suitability of hemlock for veneer-based products depends on veneer peeling characteristics and the physical and mechanical properties of veneer. Gluing properties and product strength are also important factors affecting use of a particular species for engineered wood composite products. These aspects form the basis of this study.

2 Objectives

1. To examine, by stand of origin, the relationship between tree growth characteristics such as sapwood, heartwood and corewood and veneer qualities, stiffness and recovery; and
2. To determine the suitability of second-growth western hemlock for veneer-based composite products.

3 Methods

Veneer Peeling

A total of 27 blocks of second-growth western hemlock were allocated to this experiment. The blocks were obtained from a total of nine trees selected as representative of small, medium and large diameter trees from each of three Vancouver Island stands. The stands, fully described in Section 1, were identified in terms of location and stand density as follows: Port Hardy 580 stems/ha (PH580), Port Hardy 930 s/ha (PH930) and Port Renfrew 930 s/ha (PR930). The blocks were taken from above the stump, from above the eight foot mark, and from above the sixteen foot mark of each tree (See diagram in Section 1).

The blocks were first conditioned in a hot water heating chamber at a temperature of 50 °C for 24 hours until the block core temperature reached 38 - 42 °C. Three lathe settings were used to peel the blocks with Forintek's 4-foot lathe. The lathe setup software (Peeling 1.2) developed at Forintek was used to check the lathe settings beforehand by observing the relative positions of block, knife and roller bar and the change of compression ratio (CR) during peeling. Before peeling, the blocks were marked to track their stand of origin.

Veneer was peeled to a target thickness of 0.132 inch using three different lathe settings as shown in Table 5-1. Three settings were used to determine if veneer quality could be optimized by selecting the best lathe setting. The compression ratios for settings 1, 2 and 3 dropped during peeling from 13.98 to 6.45 percent, 10.01 to 0.32 percent, 17.31 to 12.21 percent, respectively. One of the 27 blocks spun out. It was the largest bolt with a fast early growth rate and a low-density core. (Another bolt was damaged during sawing and could not be used.) Veneer recovery was determined by measuring the block diameters after round up, the core diameters at the end of the peel, and the total veneer length after peel. These measurements were entered into a Forintek veneer software program (VYield 1.2), which calculates full-size green veneer yield of each block. The veneer ribbon was sliced into 2 feet by 4 feet sheets using a pneumatic clipper and stacked into separate piles for each block.

Veneer Quality Evaluation

Six veneer sample sheets of 2 feet by 4 feet representative of sap, heart and core were randomly selected from each ribbon. In order to measure veneer thickness variation, lathe check depths and veneer roughness, two veneer strips of 2 inch width were tailored in direction parallel to grain from each sample sheet. Then, each strip was cut in equal length to 3 short sub-strips. Hence, a total of 36 green sub-strips were generated per block for the measurement of veneer thickness, roughness and lathe check depth. After lathe check depth, and surface roughness were evaluated in green

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Table 5 *Lathe Settings for Veneer Peeling*

Settings	Block No	Pitch Angle (°)	Knife Angle (°)	Knife Height (in)	Vertical Gap (in)			Horizontal Gap (in)		
					Target	Measurement		Target	Measurement	
						Left	Right		Left	Right
1	1-16	90	22	0	0.450	0.458	0.453	0.100	0.107	0.100
2	17-21	90	22	0	0.530	0.531	0.530	0.100	0.104	0.097
3	22-25	90	22	0	0.370	0.378	0.373	0.100	0.104	0.096

condition, all veneer sub-strips were oven-dried to moisture content between 3 and 5 percent. Veneer thickness variation was measured in both green and dry conditions. In order to perform stress wave testing and to make LVL, two 15 x 15 inch sub-sheets were further cut from each of the veneer sample sheets, which yielded a total of 288 sub-sheets. An additional 253 pieces of 15 x 15 inch veneer samples were also collected from the separate piles based on the volume of individual blocks to represent the population of veneer. Therefore, a total of 541 veneer samples were generated from all the peeler blocks. Before stress wave testing, these sub-sheets were dried in an oven to between 3 and 5 percent moisture content.

Stress Wave Testing

A laboratory unit of Metriguard Stress Wave Timer (Model 239A) was used for grading dry veneer. Before testing, a series of lines denoting the stress wave path in the direction parallel to the grain were drawn with an interval of 1.5 inches on the loose side of each veneer sheet. The stress wave propagation time was determined by a stress wave transmitting from a transmitting transducer and a receiving transducer through veneer sheets (Metriguard, 1998). In this study, this transmitting distance was set at 13 inches.

Nine readings were taken to derive stress wave test statistics for each veneer sheet. The dynamic modulus of elasticity of veneer, MOE_d, was computed by:

$$MOE_d = v^2 d/g$$

Where:

- **v** is the wave velocity which equals the distance divided by the stress wave propagation time,
- **d** is the gross mass density, and
- **g** is the gravity acceleration.

After the stress grading, veneer sheets were segregated into 5 groups (G1, G2, G3, G4 and G5) in more or less equal amount according to their dynamic MOEs. Then veneer sheets within the same group were used to make LVL billets.

LVL Manufacturing

A PF resin was applied at a spread rate of 70 lbs /1000 ft^2 of double glueline. Each LVL assembly was composed of 13-ply veneer sheets using the same grade. These 13-ply 15 x 15 inch assemblies were pressed at 155°C and 200 psi until the inner glueline reached 115°C. This usually required a pressing time of 31 to 35 minutes.

Mechanical Testing

After pressing, LVL panels were stacked for at least 6 hours to post-cure. Then they were cut to obtain specimens for mechanical tests. Two types of mechanical tests were performed: edgewise bending and block shear. Six replicates for each test were used. The specimen cutting pattern is shown in Figure 5-1.

Edgewise bending samples (0.4x1.55x12.0 inches) were tested on an Instron testing machine for both MOE and MOR determination. A span-to-depth ratio of 24 was used. For characterizing block shear strength, two types of shear were tested according to ASTM 1037: longitudinal shear (1.55x2.0x2.5 inches) and through-thickness shear (1.55x2.0x3.0 inches). The shear area for these samples was set at approximately 4.0 in^2. Moisture content and dry

Figure 5-1

Specimen Cutting Pattern (1–longitudinal shear; 2–shear through-thickness; 3–edgewise bending; 4–spare)

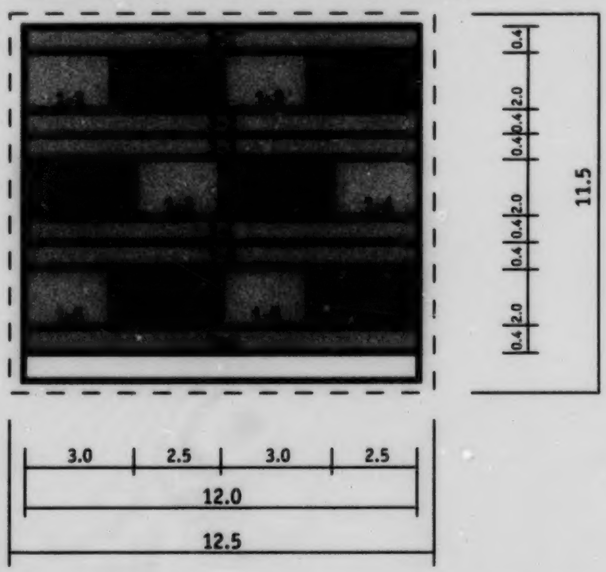


Table 5-2 *Veneer Quality and Recovery at Three Peeling Conditions (inches)*

Settings	Log Diameter		Round-up Diameter	Core Diameter	Veneer Thickness		Lathe check (%)		Roughness Grade**	Recovery (%)***	
	Small End	Large End			Average	STD*	Average	STD*		Theoretical	Actual
	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)			
1	12.70	13.71	10.98	5.57	0.131	0.005	66.26	8.45	2.39	51.28	53.49
2	13.72	14.70	12.33	5.54	0.135	0.006	65.85	11.47	3.32	59.42	62.23
3	16.09	17.47	13.87	5.69	0.138	0.009	48.92	11.91	2.97	55.36	58.39
Average****	13.33	14.62	11.63	5.58	0.133	0.006	63.37	9.53	2.67	53.85	56.52

Note:
* *standard deviation*
** *veneer roughness grade scale with 1 denoting very smooth and 9 very rough (Northcott and Walser, 1965)*
*** *full-width veneer recovery*
**** *weighted average*

density of the test samples were determined using the oven drying method.

4 Results and Discussion

Veneer Peeling Quality

Veneer quality and recovery statistics are presented in Table 5-2.

Veneer Thickness Variation and Roughness Grade

The overall average veneer thickness was 0.133 inch, which was slightly thicker than the target thickness of 0.132 inch. The average thickness for setting 1 equalled 0.131 inch, whereas those for other two settings were 0.135 and 0.138 inch, respectively. In terms of veneer thickness deviation, setting 1 was as low as 0.005 inch compared to 0.006 inch for setting 2 and 0.009 inch for setting 3. This demonstrates that setting 1 should be employed in order to minimize thickness variation.

The overall average roughness grade was 2.7, where 9 represents the roughest case. In general, veneer surface was fairly smooth. However, the veneer surface was smoother in setting 1 than settings 2 and 3, which illustrates that it is possible to peel smoother western hemlock veneer using a moderate compression ratio rather than using high compression (setting 3) or shallow compression (setting 2).

The veneer thickness variation and roughness grade also varies with different stands. As indicated in Figure 5-2, both roughness and thickness variation were higher in PH580 than PR930 and PH930. In terms of thickness variation and roughness, the best veneer was peeled from PR930 and the worst from PH580. It appears that smoother and more uniform veneer can be peeled from slower grown, higher density logs.

Lathe Checks

The average lathe check depth was 63.4 percent (percentage of check depth over veneer thickness) with a standard deviation of 9.5 percent. Its trend was, however, different from those of veneer thickness variation and roughness grade. Setting 3 produced the lowest lathe check depth of 48.9 percent, which can be attributed to the highest compression applied during peeling. Lathe check is generally an attribute controlled more by lathe setting, than by wood characteristics.

Figure 5-2
Relationship between Thickness Variation, Roughness and Stands

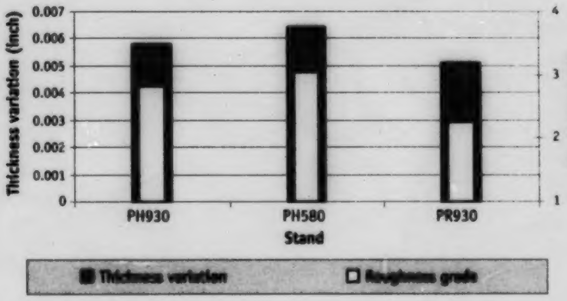
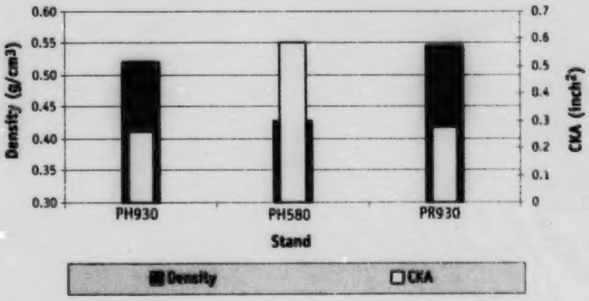


Figure 5-3
Veneer Density and Knot Distribution by Stand



Density and Knots

Knots in each veneer sheet were measured as Cumulative Knot Area (CKA). The relationships between veneer density, knot presence and stand are shown in Figure 5-3. It is

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3	22-25	90	22	0	0.370	0.378	0.373	0.100	0.104	0.096

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LVL Manufacturing

A PF resin was applied at a spread rate of 70 lbs /1000 ft² of double glueline. Each LVL assembly was composed of 13-ply veneer sheets using the same grade. These 13-ply 15 x 15 inch assemblies were pressed at 155°C and 200 psi until the inner glueline reached 115°C. This usually required a pressing time of 31 to 35 minutes.

Mechanical Testing

After pressing, LVL panels were stacked for at least 6 hours to post-cure. Then they were cut to obtain specimens for mechanical tests. Two types of mechanical tests were performed: edgewise bending and block shear. Six replicates for each test were used. The specimen cutting pattern is shown in Figure 5-1.

Edgewise bending samples (0.4x1.55x12.0 inches) were tested on an Instron testing machine for both MOE and MOR determination. A span-to-depth ratio of 24 was used. For characterizing block shear strength, two types of shear were tested according to ASTM 1037: longitudinal shear (1.55x2.0x2.5 inches) and through-thickness shear (1.55x2.0x3.0 inches). The shear area for these samples was set at approximately 4.0 in². Moisture content and dry

Figure 5-1

Specimen Cutting Pattern (1–longitudinal shear; 2–shear through-thickness; 3–edgewise bending; 4–spare)

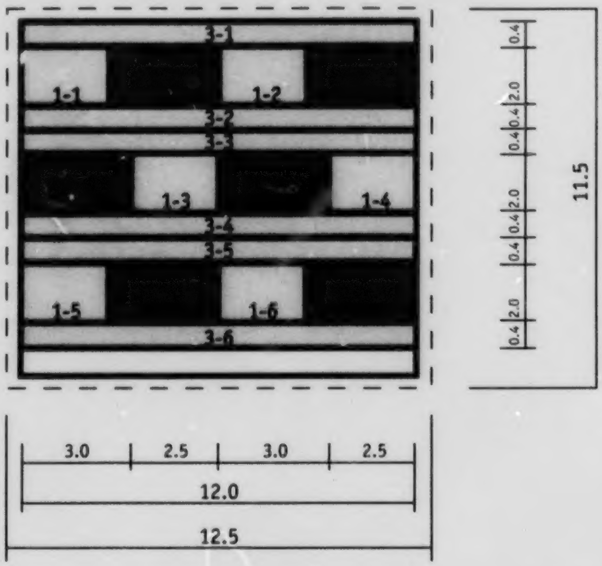


Table 5-2 *Veneer Quality and Recovery at Three Peeling Conditions (inches)*

Settings	Log Diameter		Round-up Diameter	Core Diameter	Veneer Thickness		Lathe check (%)		Roughness Grade**	Recovery (%)***	
	Small End	Large End			Average	STD*	Average	STD*		Theoretical	Actual
	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)	(inches)			
1	12.70	13.71	10.98	5.57	0.131	0.005	66.26	8.45	2.39	51.28	53.49
2	13.72	14.70	12.33	5.54	0.135	0.006	65.85	11.47	3.32	59.42	62.23
3	16.09	17.47	13.87	5.69	0.138	0.009	48.92	11.91	2.97	55.36	58.39
Average****	13.33	14.62	11.63	5.58	0.133	0.006	63.37	9.53	2.67	53.85	56.52

Note: * *standard deviation*
** *veneer roughness grade scale with 1 denoting very smooth and 9 very rough (Northcott and Walser, 1965)*
*** *full-width veneer recovery*
**** *weighted average*

density of the test samples were determined using the oven drying method.

4 Results and Discussion

Veneer Peeling Quality

Veneer quality and recovery statistics are presented in Table 5-2.

Veneer Thickness Variation and Roughness Grade

The overall average veneer thickness was 0.133 inch, which was slightly thicker than the target thickness of 0.132 inch. The average thickness for setting 1 equalled 0.131 inch, whereas those for other two settings were 0.135 and 0.138 inch, respectively. In terms of veneer thickness deviation, setting 1 was as low as 0.005 inch compared to 0.006 inch for setting 2 and 0.009 inch for setting 3. This demonstrates that setting 1 should be employed in order to minimize thickness variation.

The overall average roughness grade was 2.7, where 9 represents the roughest case. In general, veneer surface was fairly smooth. However, the veneer surface was smoother in setting 1 than settings 2 and 3, which illustrates that it is possible to peel smoother western hemlock veneer using a moderate compression ratio rather than using high compression (setting 3) or shallow compression (setting 2).

The veneer thickness variation and roughness grade also varies with different stands. As indicated in Figure 5-2, both roughness and thickness variation were higher in PH580 than PR930 and PH930. In terms of thickness variation and roughness, the best veneer was peeled from PR930 and the worst from PH580. It appears that smoother and more uniform veneer can be peeled from slower grown, higher density logs.

Lathe Checks

The average lathe check depth was 63.4 percent (percentage of check depth over veneer thickness) with a standard deviation of 9.5 percent. Its trend was, however, different from those of veneer thickness variation and roughness grade. Setting 3 produced the lowest lathe check depth of 48.9 percent, which can be attributed to the highest compression applied during peeling. Lathe check is generally an attribute controlled more by lathe setting, than by wood characteristics.

Figure 5-2
Relationship between Thickness Variation, Roughness and Stands

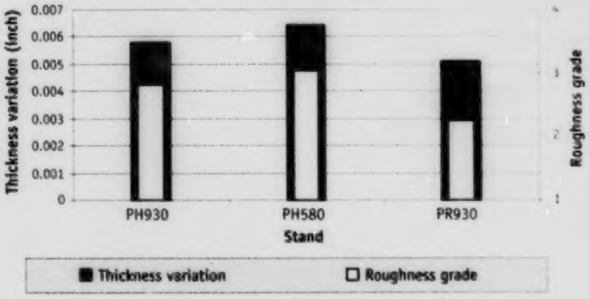
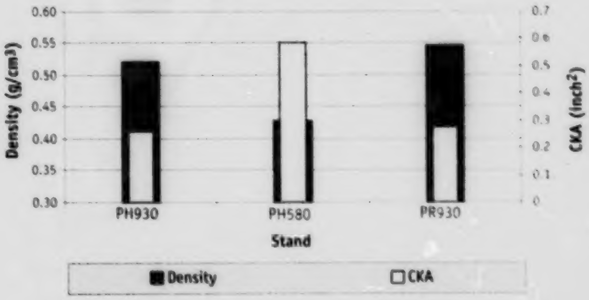


Figure 5-3
Veneer Density and Knot Distribution by Stand



Density and Knots

Knots in each veneer sheet were measured as Cumulative Knot Area (CKA). The relationships between veneer density, knot presence and stand are shown in Figure 5-3. It is

apparent that the CKA and density of PH930 are more or less the same as those of PR930. However, veneer from PH580 is considerably more knotty and of lower density.

Like many other species, average density of hemlock changes in a descending trend from sapwood, heartwood to corewood as shown in Figure 5-4. On the other hand, density variation follows the opposite trend with the highest standard deviation occurring in the core. As a result, sapwood veneer is denser and more uniform, and corewood veneer, which contains more juvenile wood, is lighter and less uniform.

Figure 5-4

Change in Veneer Density within the Block (Sap, Heart and Core)

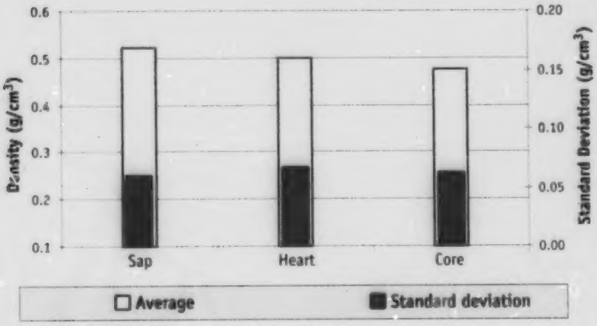
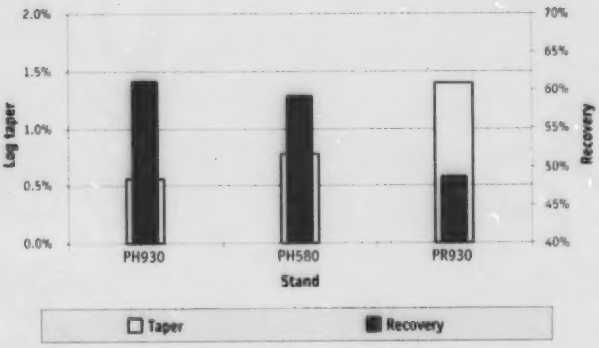


Figure 5-5

Relationship between Log Taper and Veneer Recovery by Stand



Veneer Recovery

Veneer recovery is defined as the volumetric percentage of continuous ribbon over peeler block. The actual average recovery was measured at 54%, which is 2.7% higher than the theoretical recovery predicted by the computer program (VYield1.2). The additional increase is attributed to the occurrence of opening lathe checks.

There are three main factors that can strongly affect veneer recovery. These are block diameter, taper and roundness. When peeled to the same diameter cores, blocks with larger diameter yield more veneer. As far as block shape is concerned, an ascending trend in log taper from PH930 to PR930 exists as shown in Figure 5-5. As expected, there is a descending trend in veneer recovery from PH930 to PR930.

Log roundness for both large end and small end was measured and compared between stands as shown in Figure 5-6. The results showed that the logs from PH580 are most irregular in shape, and logs from PH930 are the least.

Veneer Grades

Table 5-3 shows 541 veneer samples (15 x 15 in²) divided into 5 groups according to their dynamic MOE, which range from 0.9 to 2.6 million psi. The number of veneer samples in

Figure 5-6

Log Roundness, Veneer Recovery Change with Stands

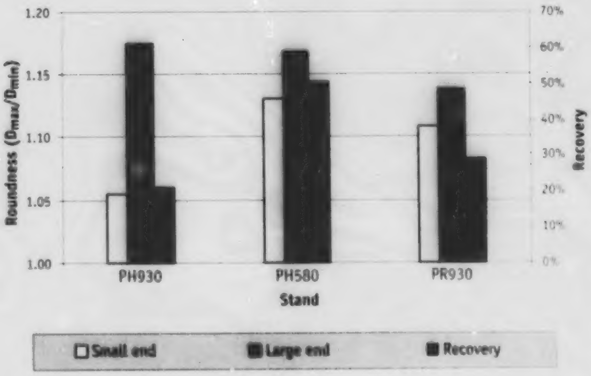


Table 5-3 *Veneer MOE and Grade for Making LVL*

Veneer MOE (10⁶ psi)	Veneer Stress Grade G5 0.9-1.3	G4 1.3-1.5	G3 1.5-1.7	G2 1.7-2.0	G1 2.0-2.6	Total
Number of veneer	94	92	139	109	107	541
Percentage	17.4%	17.0%	25.7%	20.1%	19.8%	100%
Number of LVL	7	7	10	8	8	40
Number of veneer used for LVL	91	91	130	104	104	520

apparent that the CKA and density of PH930 are more or less the same as those of PR930. However, veneer from PH580 is considerably more knotty and of lower density.

Like many other species, average density of hemlock changes in a descending trend from sapwood, heartwood to corewood as shown in Figure 5-4. On the other hand, density variation follows the opposite trend with the highest standard deviation occurring in the core. As a result, sapwood veneer is denser and more uniform, and corewood veneer, which contains more juvenile wood, is lighter and less uniform.

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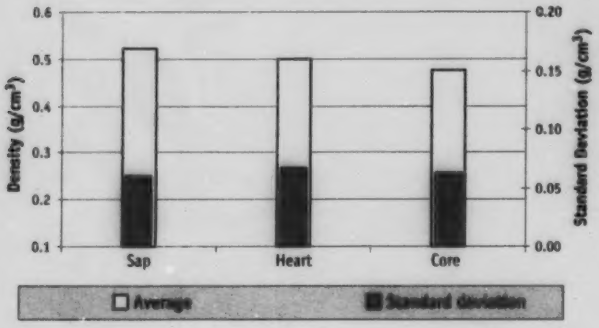

Figure 5-5
Relationship between Log Taper and Veneer Recovery by Stand

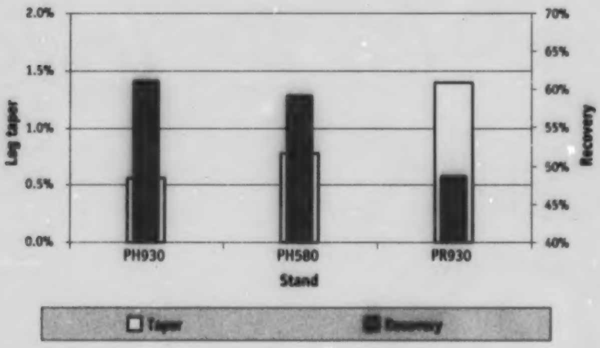

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Figure 5-6
Log Roundness, Veneer Recovery Change with Stands

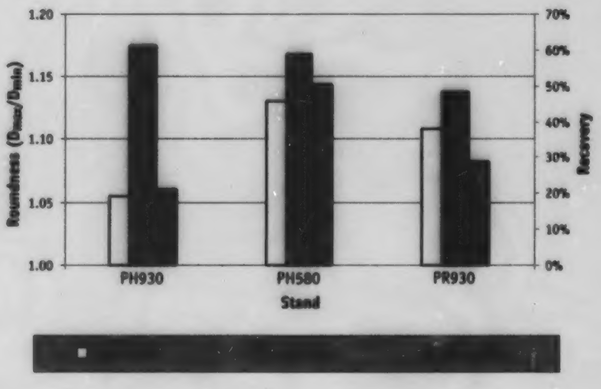


Table 5-3 *Veneer MOE and Grade for Making LVL*

Veneer MOE (10⁶ psi)	Veneer Stress Grade					Total
	65 0.9-1.3	64 1.3-1.5	63 1.5-1.7	62 1.7-2.0	61 2.0-2.6	
Number of veneer	94	92	139	109	107	541
Percentage	17.4%	17.0%	25.7%	20.1%	19.8%	100%
Number of LVL	7	7	10	8	8	40
Number of veneer used for LVL	91	91	130	104	104	520

each group amounts to about 20 percent of the total veneer sheets. From these veneer samples, forty 13-ply LVL billets can be manufactured.

Figure 5-7 shows the frequency distribution of veneer dynamic MOEs which seems to follow well the 3-parameter Weibull fitted curve. The average dynamic MOE is 1.601 million psi with a deviation of 0.337 million psi.

The results of this study indicate that veneer strength grade is affected by veneer position within blocks and by block position within trees. As expected, the sapwood, which is more mature, yields higher grade veneer, whereas the core, which has more juvenile wood, produces lower grade veneer. On average, there is a clear increasing trend from sap to core in both average stress wave times and their standard deviations (Figure 5-8). In other words, veneer stiffness generally decreases from sap to heart and core. Changes in veneer MOE with block location within the same tree were evident as shown in Figure 5-9. There is a descending trend in veneer MOE from the upper section to the bottom section.

As far as tree stand is concerned, veneer from both PH930 and PR930 was similar in terms of strength properties. The veneer MOE from PH930 and PR930 was significantly higher than that of PH580. The difference is probably attributed to proportion of mature wood that is in turn affected by differences in early growth rate. Indeed, the average log from PH580 is about 15 percent larger in diameter and 25 to 30 percent lower in veneer MOE (Figure 5-10).

LVL Properties

According to the ASTM Standard, laminated veneer lumber (LVL) is subjected to two major mechanical tests: bending and block shear. Since LVL is an oriented veneer product, most mechanical properties are orientation dependent. Due to specimen size limitation, flatwise bending could not be performed. However, there is a direct correlation between flatwise bending properties and edgewise bending properties.

For edgewise bending test, the center-point-loading configuration was adopted in this investigation with a span of a 10 inches. Considering the current LVL standards, the large

Figure 5-7
Frequency Distribution of Veneer Dynamic MOE

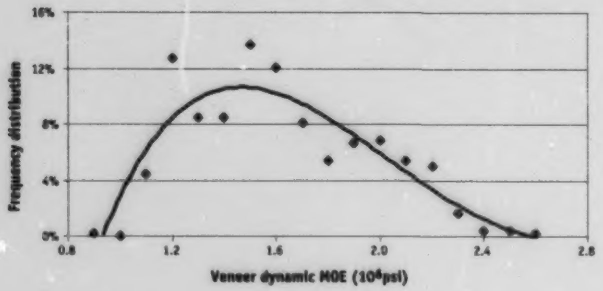


Figure 5-8
Stress Wave Time Changes with Sap, Heart and Core

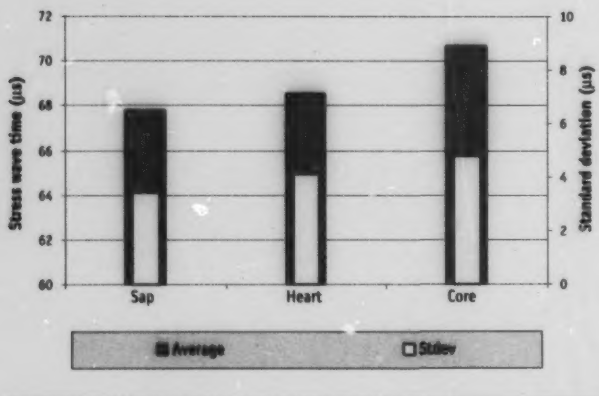


Figure 5-9
Relationship between Veneer MOE and Sap, Heart and Core at Different Block Positions

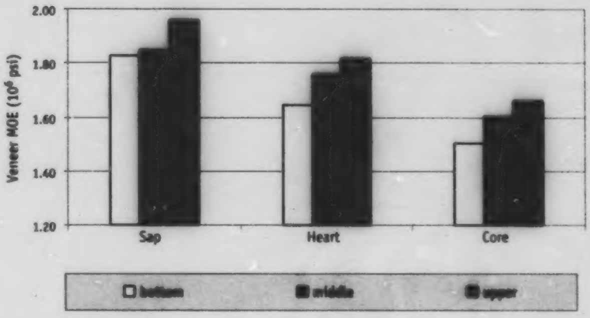
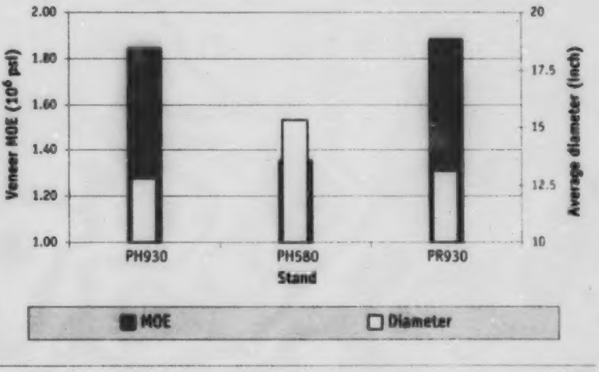


Figure 5-10
Relationship between Veneer MOE, Average Block Diameter and Stand



specimen third-point-bending test should be performed for strength determination. Therefore, the edgewise-bending test results obtained using center-point loading need to be calibrated to those using third-point loading. Generally, it was found that the edgewise bending MOE using third-point loading is about 20 percent higher than that using center-point loading, and edgewise bending MOR using third-point loading is approximately 20 percent lower than that using center-point loading. Hence, a conversion factor of 1.2 could be used for estimation of edgewise bending properties of LVL.

Relationship Between Bending Strength and Veneer Grade

Table 5-4 shows that the overall average MOE of LVL determined using centre-point loading was 1.77 million psi, which is equivalent to 2.12 million psi using third-point bending test. This property exceeds the market standard (1.8 million psi), and is also close to that of Douglas fir LVL. The MOE and MOR of LVL in each group appear to be closely correlated to veneer MOE grades. LVL made with higher-grade veneer possesses higher bending strength properties.

The relationships between LVL MOE and veneer MOE are plotted in Figure 5-11. The results show that the correlation between LVL MOE and veneer MOE is highly significant with $r^2 = 0.95$. The close correlation suggests that MOE of LVL can be accurately predicted using the veneer dynamic MOE obtained by stress grading. It is worth noting that the slope is greater than 1 and the intercept is positive, which indicates an increase in LVL MOE from veneer MOE. Such property improvement is common in veneer-based composite products due to the addition of resin during manufacturing.

The relationship between LVL MOR and LVL MOE is plotted in Figure 5-12. The results indicate a high degree of correlation exists between MOR and MOE with $r^2 = 0.95$. This suggests that hemlock LVL MOR may also be calculated based on LVL MOE or veneer MOE. Such a close correlation is useful for engineered applications of Hemlock LVL.

Figure 5-11

Relationship between LVL MOE and Veneer MOE (Center-point Edgewise Bending)

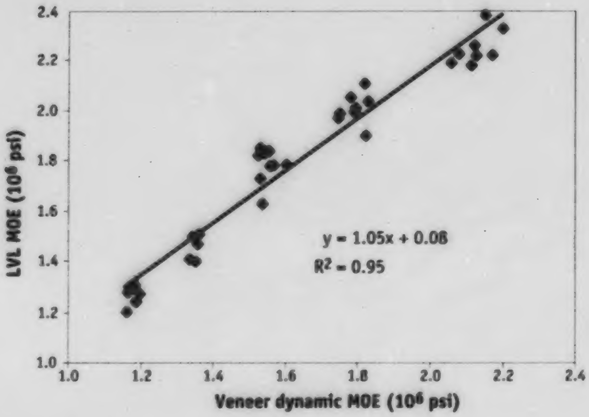


Figure 5-12

Relationship between LVL MOR and MOE (Center-point Edgewise Bending)

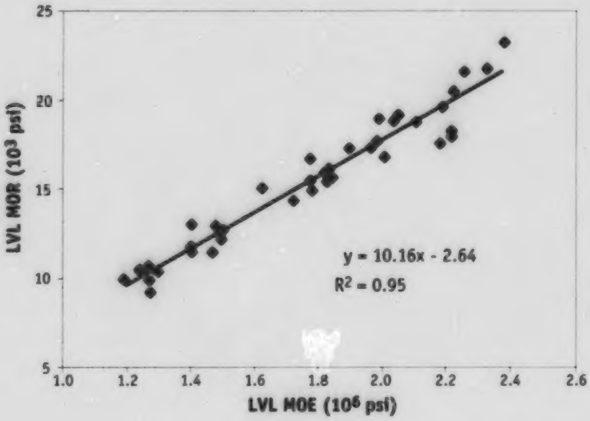


Table 5-4 *Experimental Results of LVL Center-point Edgewise Bending*

Veneer Grade	Veneer MOE (10^6 psi)	LVL MOE (10^6 psi)					LVL MOR (10^3 psi)					LVL Density (g/cm³)	MC*** (%)	No. of pieces
		Average	STD*	Max.	Min.	COV(%)**	Average	STD*	Max.	Min.	COV(%)**			
G1	2.0-2.6	2.25	0.15	2.58	1.80	6.76	19.98	2.25	24.64	15.82	11.28	0.622	5.57	48
G2	1.7-2.0	2.01	0.13	2.22	1.53	6.68	18.05	1.44	21.43	14.58	7.95	0.583	5.69	48
G3	1.5-1.7	1.79	0.11	1.99	1.53	6.33	15.47	1.20	17.90	12.39	7.79	0.531	5.97	60
G4	1.3-1.5	1.45	0.14	1.85	1.10	9.34	12.19	1.48	15.85	9.24	12.17	0.503	6.39	42
G5	0.9-1.3	1.26	0.10	1.48	1.05	7.56	10.07	1.05	13.57	7.99	10.40	0.486	6.26	42
Overall		1.77	0.37	2.58	1.05	20.90	15.52	4.65	24.64	7.99	30.00	0.545	5.98	Total 240

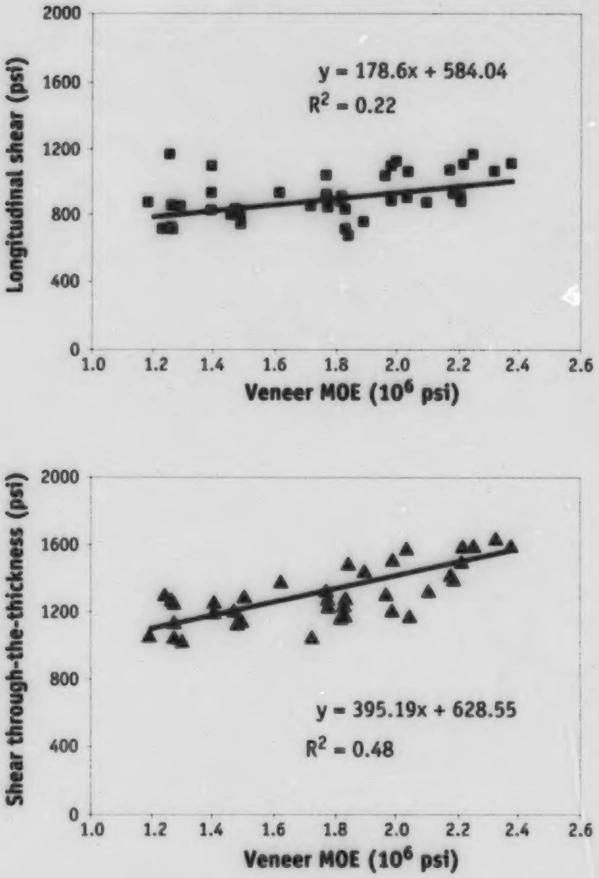
Note:
* *standard deviation*
** *coefficient of variation*
*** *moisture content*

Table 5-5 *Experimental Results of LVL Block Shear Test*

Veneer Grade	Veneer MOE (10^6 psi)	LVL Longitudinal Shear (psi)					LVL Shear through-the-thickness (psi)					MC*** (%)	No. of pieces
		Average	STD*	Max.	Min.	COV(%)**	Average	STD*	Max.	Min.	COV(%)**		
G1	2.0-2.6	1031.5	172.9	1480.7	751.5	16.8	1597.0	141.2	2038.0	1346.4	8.8	6.00	48
G2	1.7-2.0	977.7	179.4	1349.2	556.4	18.4	1431.8	246.5	2007.1	1090.3	17.2	6.20	48
G3	1.5-1.7	853.2	157.2	1373.8	577.5	18.4	1262.3	152.8	1574.1	884.9	12.1	6.40	60
G4	1.3-1.5	856.1	191.7	1323.9	547.0	22.4	1211.2	127.0	1472.2	873.6	10.5	6.60	42
G5	0.9-1.3	831.8	209.4	1421.5	415.1	25.2	1158.7	167.8	1504.5	702.6	14.5	6.70	42
Overall		908.2	195.8	1480.7	415.1	21.6	1336.1	233.2	2038.0	702.6	17.5	6.40	Total 240

Note: ** standard deviation ** coefficient of variation ***moisture content*

Figure 5-13
Relationship between LVL Shear Strengths and Veneer MOE



Block Shear Strength

It appears from Table 5-5 that both longitudinal shear strength and through-the-thickness shear strength are affected by veneer grades. However, the magnitude of the effects differs. The shear through-the-thickness strength decreases more as the veneer grade goes down than does the longitudinal shear strength. In addition, LVL panels assembled with the veneer grades of G1, G2, G3 appear to show more significant changes with veneer grade than those constructed with the lower grades G4, and G5.

To illustrate their correlation with veneer grades, both shear strengths are shown plotted against veneer MOE in Figure 5-13. The correlation between LVL longitudinal shear and veneer MOE appears to be relatively weak with $r^2 = 0.22$. In contrast, the correlation between LVL shear through-the-thickness and veneer MOE was higher with $r^2 = 0.48$.

LVL Grades

The current market-standard for LVL strength calls for 1.8 million psi MOE in structural applications. Given the correlation between LVL center-point bending MOE and veneer MOE, and the correlation between LVL center-point and LVL third-point bending, an estimated conversion factor of 1.3 can be used to assess the percentage of veneer sheets which could be used to make LVL that meets the market standard. Based on Table 5-4, multiplying the veneer MOE (average) by the 1.3 conversion factor, it can be seen that veneer grade G1, G2, G3 and G4 are suitable for making LVL with a minimum 1.8 million psi MOE requirement. Relating the veneer grade to number of LVL samples (no. of pieces) generated, it can be shown that about 82.5 percent of total hemlock LVL panels meet this minimum requirement. Furthermore, 65.0 percent of the total hemlock LVL panels meet a 2.0 million psi MOE requirement, and could be used for a higher grade LVL. The 17.5 percent of total hemlock LVL panels not meeting these requirements could either be used for lower grade LVL or for plywood.

5 Conclusions

Second-growth western hemlock is a peelable species which can be used for LVL products when obtained from stands of slow growth rate (PH930 and PR930), and for plywood products when obtained from stands of fast growth rate (PH580).

- Lathe settings significantly affect veneer quality in terms of surface roughness, thickness variation and lathe specimen third-point-bending test should be performed for strength determination. Therefore, the edgewise-bending test results obtained using center-point loading need to be calibrated to those using third-point loading. Generally, it was found that the edgewise bending MOE using third-point loading is about 20 percent higher than that using center-point loading, and edgewise bending MOR using third-point loading is approximately 20 percent lower than that using center-point loading. Hence, a conversion factor of 1.2 could be used for estimation of edgewise bending properties of LVL.

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The relationships between LVL MOE and veneer MOE are plotted in Figure 5-11. The results show that the correlation between LVL MOE and veneer MOE is highly significant with $r^2 = 0.95$. The close correlation suggests that MOE of LVL can be accurately predicted using the veneer dynamic MOE obtained by stress grading. It is worth noting that the slope is greater than 1 and the intercept is positive, which indicates an increase in LVL MOE from veneer MOE. Such property improvement is common in veneer-based composite products due to the addition of resin during manufacturing.

The relationship between LVL MOR and LVL MOE is plotted in Figure 5-12. The results indicate a high degree of correlation exists between MOR and MOE with $r^2 = 0.95$. This suggests that hemlock LVL MOR may also be calculated based on LVL MOE or veneer MOE. Such a close correlation is useful for engineered applications of Hemlock LVL.

Figure 5-11
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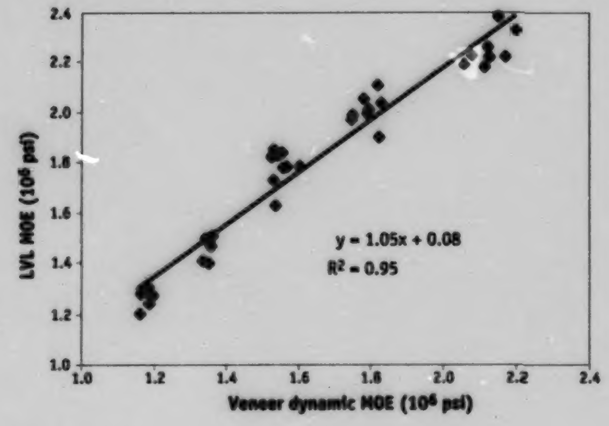
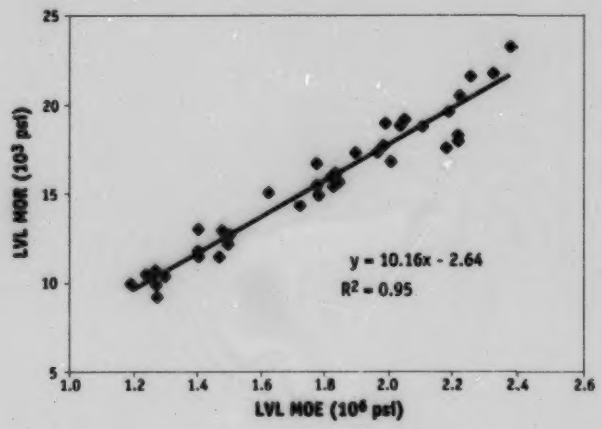


Figure 5-12
Relationship between LVL MOR and MOE (Center-point Edgewise Bending)



[illegible] *Experimental Results of LVL Center-point Edgewise Bending*

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		Average	STD*	Max.	Min.	COV(%)**	Average	STD*	Max.	Min.	COV(%)**			
G1	2.0-2.6	2.25	0.15	2.58	1.80	6.76	19.98	2.25	24.64	15.82	11.28	0.622	5.57	48
G2	1.7-2.0	2.01	0.13	2.22	1.53	6.68	18.05	1.44	21.43	14.58	7.95	0.583	5.69	48
G3	1.5-1.7	1.79	0.11	1.99	1.53	6.33	15.47	1.20	17.90	12.39	7.79	0.531	5.97	60
G4	1.3-1.5	1.45	0.14	1.85	1.10	9.34	12.19	1.48	15.85	9.24	12.17	0.503	6.39	42
G5	0.9-1.3	1.26	0.10	1.48	1.05	7.56	10.07	1.05	13.57	7.99	10.40	0.486	6.26	42
Overall		1.77	0.37	2.58	1.05	20.90	15.52	4.65	24.64	7.99	30.00	0.545	5.98	Total 240

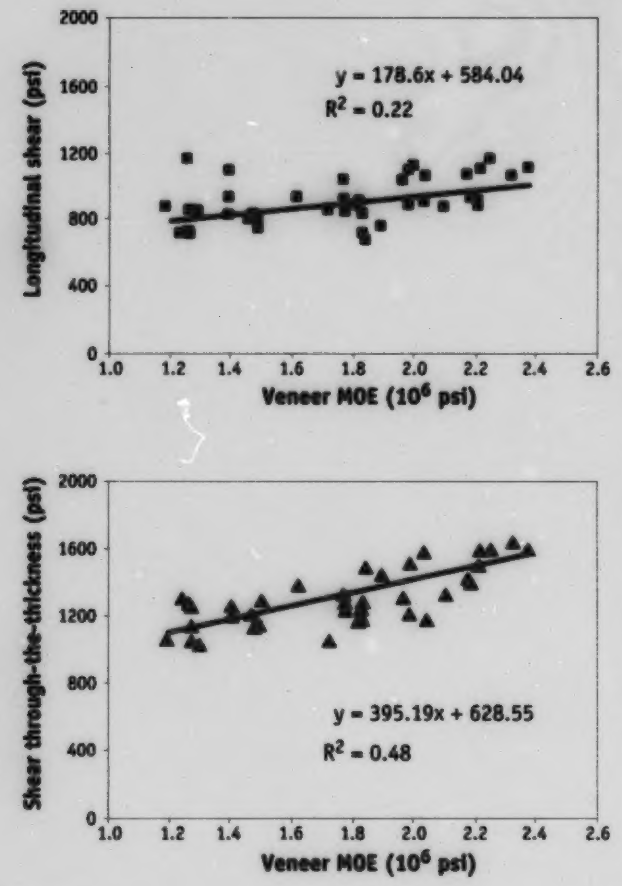
Note:
* *standard deviation*
** *coefficient of variation*
*** *moisture content*

Experimental Results of LVL Block Shear Test

Veneer Grade	Veneer MOE (10^6 psi)	LVL Longitudinal Shear (psi)					LVL Shear through-the-thickness (psi)					MC*** (%)	No. of pieces
		Average	STD*	Max.	Min.	COV(%)**	Average	STD*	Max.	Min.	COV(%)**		
G1	2.0-2.6	1031.5	172.9	1480.7	751.5	16.8	1597.0	141.2	2038.0	1346.4	8.8	6.00	48
G2	1.7-2.0	977.7	179.4	1349.2	556.4	18.4	1431.8	246.5	2007.1	1090.3	17.2	6.20	48
G3	1.5-1.7	853.2	157.2	1373.8	577.5	18.4	1232.3	152.8	1574.1	884.9	12.1	6.40	60
G4	1.3-1.5	856.1	191.7	1323.9	547.0	22.4	1211.2	127.0	1472.2	873.6	10.5	6.60	42
G5	0.9-1.3	831.8	209.4	1421.5	415.1	25.2	1158.7	167.8	1504.5	702.6	14.5	6.70	42
Overall		908.2	195.8	1480.7	415.1	21.6	1336.1	233.2	2038.0	702.6	17.5	6.40	Total 240

Note: ** standard deviation ** coefficient of variation ***moisture content*

Figure 5-13
Relationship between LVL Shear Strengths and Veneer MOE



Block Shear Strength

It appears from Table 5-5 that both longitudinal shear strength and through-the-thickness shear strength are affected by veneer grades. However, the magnitude of the effects differs. The shear through-the-thickness strength decreases more as the veneer grade goes down than does the longitudinal shear strength. In addition, LVL panels assembled with the veneer grades of G1, G2, G3 appear to show more significant changes with veneer grade than those constructed with the lower grades G4, and G5.

To illustrate their correlation with veneer grades, both shear strengths are shown plotted against veneer MOE in Figure 5-13. The correlation between LVL longitudinal shear and veneer MOE appears to be relatively weak with $r^2 = 0.22$. In contrast, the correlation between LVL shear through-the-thickness and veneer MOE was higher with $r^2 = 0.48$.

LVL Grades

The current market-standard for LVL strength calls for 1.8 million psi MOE in structural applications. Given the correlation between LVL center-point bending MOE and veneer MOE, and the correlation between LVL center-point and LVL third-point bending, an estimated conversion factor of 1.3 can be used to assess the percentage of veneer sheets which could be used to make LVL that meets the market standard. Based on Table 5-4, multiplying the veneer MOE (average) by the 1.3 conversion factor, it can be seen that veneer grade G1, G2, G3 and G4 are suitable for making LVL with a minimum 1.8 million psi MOE requirement. Relating the veneer grade to number of LVL samples (no. of pieces) generated, it can be shown that about 82.5 percent of total hemlock LVL panels meet this minimum requirement. Furthermore, 65.0 percent of the total hemlock LVL panels meet a 2.0 million psi MOE requirement, and could be used for a higher grade LVL. The 17.5 percent of total hemlock LVL panels not meeting these requirements could either be used for lower grade LVL or for plywood.

5 Conclusions

Second-growth western hemlock is a peelable species which can be used for LVL products when obtained from stands of slow growth rate (PH930 and PR930), and for plywood products when obtained from stands of fast growth rate (PH580).

- Lathe settings significantly affect veneer quality in terms of surface roughness, thickness variation and lathe checks. Setting 1, which resulted in a wood compression of 13% is recommended for optimum peeling of second-growth western hemlock.

- While veneer recovery is mainly controlled by log diameter, taper and roundness, veneer strength properties appear to be affected by growth rate.
- With slower growth rate, both PH930 and PR930 yield similar veneer, which is smoother and more uniform, and stronger than that from PH580. Therefore, they are more suitable for LVL production.
- PH580 produced larger diameter trees, which are, however, knotty and relatively low in density. These would be suitable for plywood production because of their high recovery.
- Like other species, western hemlock veneer decreases in quality and strength from sap to heart and to core, as well as from the top to the bottom of the stem.
- Hemlock LVL strength properties, which are close to those of Douglas-fir LVL, are highly correlated to veneer stress grades. In particular, the bending strength (both MOE and MOR) of LVL can be accurately predicted based on veneer MOE which can be evaluated using the non-destructive stress wave test.
- Including all the hemlock bolts studied, about 82.5 percent can be used for making structural LVL and 65.0 percent meet the high-grade market standard (2.0 million psi).

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SECTION

6

TREATABILITY OF SECOND-GROWTH WESTERN HEMLOCK

Paul I. Morris and Shane M. McFarling

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TREATABILITY OF SECOND-GROWTH WESTERN HEMLOCK

SECTION

6

1 Objective

To evaluate the treatability, with water-borne and solvent-borne preservatives, of second-growth western hemlock from two locations in British Columbia.

2 Introduction

Preservative treatment of lumber, timbers, plywood and round-wood is a key tool in maintaining and expanding markets for wood products in applications conducive to decay and insect damage. Canada is unlucky to have some of the least treatable wood species in the world. Western hemlock (*Tsuga Heterophylla* Raf. Sarg.) has traditionally been regarded as one of our more treatable Canadian Wood Species. This perception was questioned by Morris (1995) who found that the reputation of hemlock for treatability had been largely carried by the treatability of Amabilis fir (*Abies amabilis* [Dougl] Forbes.) which is sold together with hemlock as hem-fir. Amabilis fir was found to be almost twice as treatable as western hemlock. Double-density incised hemlock, treated under pressure for six hours, could not reliably meet the penetration requirements in Canadian standards for ground contact applications. In contrast single-density incised amabilis fir treated under pressure for three hours easily met the standard. Particular problems have been encountered in the treatment of hemlock from dryer regions of Vancouver Island, the interior wet belt and from the north coast.

All the treatability data available and much of the industrial experience is based on old-growth hemlock. There was therefore a great need to determine what differences might be expected from second-growth.

Western hemlock has been commonly treated with waterborne preservatives for exterior uncoated applications in the USA, Japan and Canada. It has also been commonly treated with solvent-borne preservatives for exterior coated applications in Europe. It is therefore important to know the treatability with both types of preservative. Chromated copper arsenate (CCA) was selected as a representative water-borne preservative and Acypetacs Copper (Cuprinol) was selected as a representative European solvent-borne preservative.

3 Materials and Methods

Material Selection and Sample Preparation

Kiln dried second-growth western hemlock samples were selected from lumber obtained from two stands on Vancouver Island which were previously described. PH930 was slow/medium grown hemlock, PH580 was fast grown hemlock. The samples obtained were previously tested for engineering standards and were therefore short in length. From each site 1st juvenile (first 15 annual rings) and 2nd juvenile samples (16-30 annual rings) were selected based on a minimum of 70% of the sample being 1st or 2nd juvenile wood. The selected samples were then cut into 2 x 2 ft long end-matched samples, sub-samples A and B, and individually numbered. Table 6-1 shows the treatment groups and numbers of samples.

Table 6-1 *Treatment Groups*

Group #	Growth Rate	Juvenile Wood	No. of Samples
1	Slow/Medium	1st	13
2	Slow/Medium	2nd	10
3	Fast	1st	37
4	Fast	2nd	40

The sub-samples were end-sealed with 3 coats of a 2-part epoxy resin. The sub-samples were then stickered and placed outside under cover to allow the moisture content to equilibrate to approximately 19%. Prior to treatment the moisture content was checked with a Delmhorst moisture meter.

Pressure Treatment

From each group, sub-sample A, was treated with 2.5% CCA using the following full cell pressure treatment schedule:

- 30 minutes up to full vacuum (740 mm Hg)
- Fill retort under vacuum
- 10 minutes to raise pressure to 690 kPa
- 360 minutes at variable pressure – 862 to 1035 kPa
- 10 minutes to relieve pressure
- Empty retort
- 10 minute final vacuum (670 mm Hg)

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- 360 minutes at variable pressure – 862 to 1035 kPa
- 10 minutes to relieve pressure
- Empty retort
- 10 minute final vacuum (670 mm Hg)

This schedule was selected for comparison to previous work (Morris and Ingram 1993, Morris 1995) using the same schedule. It is also reasonably representative of industry schedules used to meet Canadian standards. After treatment the samples were covered and stored outside for one week to allow fixation, then uncovered for 5 days to dry.

From each group, sub-sample B, was treated with 2% Acypetacs Copper (Cuprinol) using the following double vacuum pressure treatment schedule:

- 10 minutes vacuum at 495 mm Hg
- Fill retort under vacuum
- 10 minutes at atmospheric pressure
- Empty retort
- 20 minute vacuum at 623 mm Hg

This schedule was specifically developed for western hemlock by the Building Research Establishment in the United Kingdom (Bravery *et al.* 1990). Following treatment the samples were stickered and placed outside awaiting analysis.

Each sample was weighed before and after treatment to determine solution uptake.

Sampling for Penetration and Retention

CCA and Acypetacs Copper

A core boring was taken form the heartwood face of each board within that part of the board containing the juvenile group specified. These cores were oven-dried at 50 °C for 4 hours. Each core was then cut to 16 mm in length and split longitudinally, one half for penetration measurement and the other for retention analysis. The penetration sample was sprayed with Chrome-Azurol S indicator solution (American Wood Preservers' Association, 1997a) to detect copper. For analysis the core boring halves were combined into one composite sample per set of 20 (or portion of) per group and ground to pass through a 40-mesh screen. 0.4 g of each composite sample was then combined with 0.1 g of cellulose and compressed to form a pellet. These pellets were analysed on a Tracor Northern energy-dispersive X-ray spectrometer which had been calibrated for chromium, copper and arsenate (American Wood Preservers' Association, 1997b). Results were then converted from a weight/weight to a weight/volume basis (kg/m^3) using the specific gravity of western hemlock (Density = 410 kg/m^3), with the exception of slow/medium grown 2nd juvenile western hemlock with a density of 441 kg/m^3. Average densities were determined using increment cores taken from each tree at breast height, then calculated on a green volume/oven-dry weight basis.

Acypetacs Copper Only

In addition to the above, cross-sectioned samples were taken for penetration measurements and sprayed with Chrome-Azurol S indicator solution. Centre heartwood face, minimum and maximum penetration measurements were recorded.

Statistical analysis of the penetration data was performed on all data (CCA and Acypetacs Copper) using the analysis of variance method.

4 Results and Discussion

The limited number of samples of slow/medium grown PH930 material available made it difficult to draw firm conclusions for this type of material.

Penetration

CCA

When comparing slow/medium grown hemlock to fast grown (Table 6-2) only the 1st juvenile wood showed a difference in mean penetration, although these differences were not statistically different. The fast grown, 1st juvenile wood had a 25% higher mean penetration than slow/medium-grown, 1st juvenile hemlock. 2nd juvenile wood showed little difference between fast and slow/medium grown.

2nd juvenile wood was significantly more treatable than 1st juvenile wood. 2nd juvenile wood showed a 102% deeper penetration for slow/medium grown and a 56% deeper penetration for fast grown hemlock compared to 1st juvenile wood (Figure 1).

Table 6-2 *Results for Second-growth Hemlock Treated with CCA*

Growth rate	Juvenile	Retention (kg/m^3)	Penetration		
			Mean (mm)	% ≥ 10 mm	% ≥ 5 mm
Slow/medium	1st	10.4	6.7 (4.8)	23	54
Slow/medium	2nd	16.0	13.5 (4.8)	80	90
Fast	1st	15.5	8.4 (5.0)	41	73
Fast	2nd	20.0	13.1 (4.3)	73	95

NOTE: Standard deviations are in parentheses

This schedule was selected for comparison to previous work (Morris and Ingram 1993, Morris 1995) using the same schedule. It is also reasonably representative of industry schedules used to meet Canadian standards. After treatment the samples were covered and stored outside for one week to allow fixation, then uncovered for 5 days to dry.

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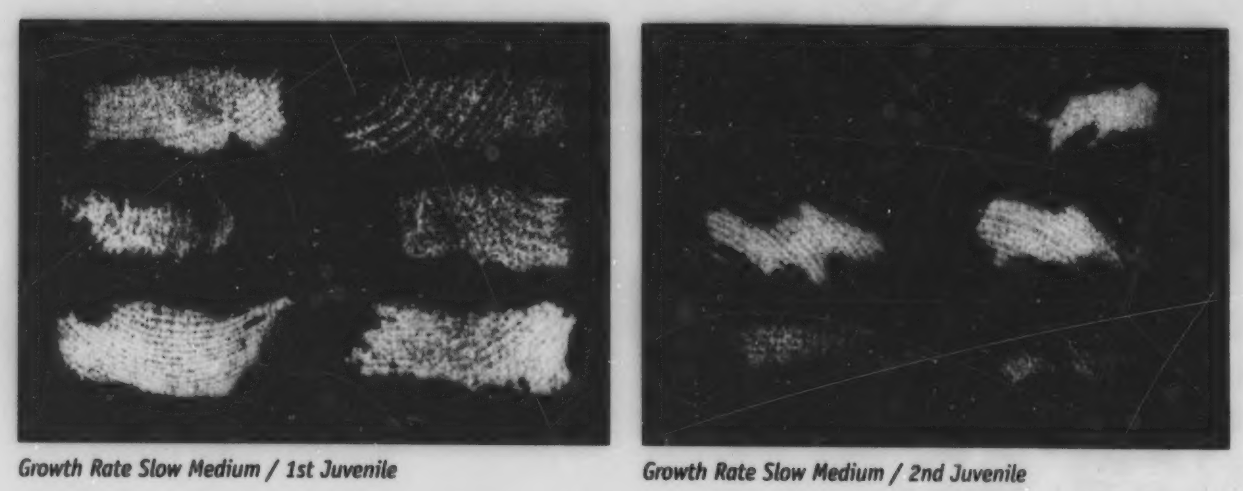
			Mean (mm)	% ≥ 10 mm	% ≥ 5 mm
Slow/medium	1st	10.4	6.7 (4.8)	23	54
Slow/medium	2nd	16.0	13.5 (4.8)	80	90
Fast	1st	15.5	8.4 (5.0)	41	73
Fast	2nd	20.0	13.1 (4.3)	73	95

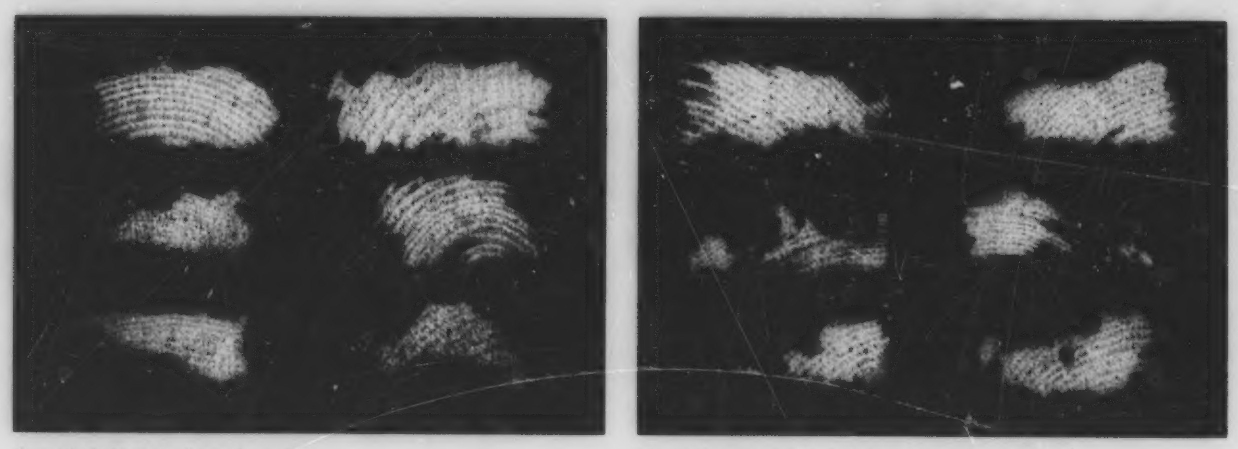
NOTE: Standard deviations are in parentheses

Figure 1
Cross-section Samples Showing CCA Penetration



Growth Rate Slow Medium / 1st Juvenile

Growth Rate Slow Medium / 2nd Juvenile



Growth Rate Fast / 1st Juvenile

Growth Rate Fast / 2nd Juvenile

Acypetacs Copper

Cores

In the case of Acypetacs Copper, significant differences between 1st and 2nd juvenile wood were only seen in fast grown hemlock (Table 6-3). 2nd juvenile wood had a 45% increase in mean penetration over 1st juvenile wood. There were no statistically significant differences between slow/medium and fast grown hemlock.

Watson (Bravery *et. al* 1990) suggested a 3 mm penetration laterally will provide adequate protection of joinery-grade western hemlock. This penetration requirement is listed as P2 in European Standard EN 351-1. All groups had a mean penetration >3 mm, but only 2nd juvenile slow/medium grown hemlock achieved 80% of the samples equal to or greater than 3 mm. Core borings are typically used in North America, but Europe appears to be moving towards destructive sampling of cross sections.

Cross Sections

Fast grown hemlock had higher centre heartwood face mean penetration levels (Table 6-4) than slow/medium grown hemlock, although not statistically significant. Mean minimum penetrations were also generally higher for fast grown hemlock.

All groups met the target penetration of 3 mm and 80% of the samples equal to or greater than 3 mm penetration. The deeper penetration in cross sections compared to borings may be due to a tendency for residual solvent to creep over the cut surfaces increasing the apparent penetration in cross sections.

Retention

CCA

Treatment results for the CCA treated material (Table 6-2) showed higher retention for fast grown hemlock than for slow/medium grown and higher retentions for 2nd juvenile than for 1st juvenile. Fast-grown 2nd juvenile wood had the highest retention.

Acypetacs Copper

Treatment results for the Acypetacs Copper treated material (Table 6-3) showed higher retention for fast grown hemlock than for slow/medium grown and higher retentions for 2nd juvenile than for 1st juvenile. Fast-grown 2nd juvenile wood had the highest retention.

Compliance with AWPA and CSA Standards – CCA

In the AWPA C2-98 and CSA 080.2 standards, the penetration requirement for hem-fir is for 80% of the borings to have equal or greater than 10 mm penetration. The retention requirement is 6.4 kg/m³ for ground contact and 4.0 kg/m³ for above-ground contact. These standards require incising of western hemlock.

Not surprisingly, only 2nd juvenile slow/medium grown hemlock met the AWPA C2-98 standard for penetration and retention unincised (Table 6-2). Fast grown 2nd juvenile hemlock had 73% of samples make the requirement. All groups met the ground contact retention requirement.

Table 6-3 *Results for Second-growth Hemlock Treated with Acypetacs Copper – Core Borings*

Growth Rate	Juvenile	Retention (kg/m³)	Penetration	
			Mean (mm)	% ≥ 3 mm
Slow/Medium	1st	0.70	4.0(4.2)	62
Slow/Medium	2nd	1.00	4.2(2.3)	80
Fast	1st	0.84	4.1(2.8)	59
Fast	2nd	1.58	6.0(4.5)	70

NOTE: Standard deviations are in parentheses

The CSA 080.32-97 decking standard requires 80% of borings to have equal to or greater than 5 mm penetration. Both fast and slow/medium 2nd juvenile hemlock met this standard and 1st juvenile fast grown hemlock came very close, having 73% of the samples equal to or greater than 5 mm penetration (Table 6-2). The retention requirement in CSA 080.32-97 is 6.4 kg/m³ in a 5 mm assay zone for CCA. Based on the penetration depths measured and the retention in the 16 mm assay zone, all of the groups treated would have met this retention requirement.

Comparison to 1993 Study of CCA-Treated Old-growth Hemlock

A hem-fir treatability study was carried out at Forintek in 1993 (Morris and Ingram 1993, Morris 1995). In this study hemlock from five coastal sawmills, incised and unincised, was treated with CCA using 3 and 6 hour press times. One set of sub-samples in the present study were prepared and treated as far as possible using identical procedures to one of the groups in the 1993 study: unincised and 6 hour press time. Forintek's wood preservation pilot plant has undergone a series of major upgrades in the intervening six years thus the two sets of work were done using quite different equipment. Nevertheless, since old-growth material from a similar growing site was not available for the present study, it is instructive to compare the results from the second-growth in the present study to the old growth in the 1993 study.

A CCA solution strength of 2.5% was used for both studies and the retention levels from the 1999 study (Table 6-2) were considerably higher than the 1993 study (Table 6-5). Even the most poorly treated, 1st juvenile slow/medium grown hemlock, had almost three times the retention. Considering the difficulty in improving preservative penetration using the full-cell process by adjusting process parameters, it is highly unlikely that this difference could be attributable to upgrades in the equipment.

Table 6-4 *Results for Second-growth Hemlock Treated with Acypetacs Copper – Cross Sections*

Growth Rate	Juvenile	Penetration Mean			C.H.F.* % ≥ 3 mm
		C.H.F.* (mm)	Minimum (mm)	Maximum (mm)	
Slow/Medium	1st	4.9(2.8)	2.3(1.4)	14.3(3.5)	85
Slow/Medium	2nd	5.3(1.6)	2.6(1.5)	16.7(3.5)	90
Fast	1st	6.3(3.5)	3.1(2.0)	12.7(4.9)	86
Fast	2nd	5.9(3.4)	2.9(1.5)	13.8(4.4)	90

** - Centre heartwood face   NOTE: Standard deviations are in parentheses*

Table 6-5 *1993 Study* - CCA*

Mill	Retention kg/m^3	PenetrationMean		
		(mm)	% ≥ 10 mm	% ≥ 5 mm
A	4.0	6.4 (5.9)	30 ± 20	50 ± 22
	2.6	3.8 (3.1)	5 ± 11	35 ± 21
B	3.6	6.0 (4.9)	20 ± 18	55 ± 22
	3.6	5.9 (4.7)	30 ± 20	40 ± 21
C	3.9	5.9 (4.2)	15 ± 15	55 ± 22
	2.5	4.7 (4.4)	5 ± 11	40 ± 21
D	3.1	6.1 (5.8)	30 ± 20	40 ± 21
	2.8	3.8 (4.5)	10 ± 13	25 ± 19
E	4.7	7.3 (4.9)	45 ± 22	60 ± 21
	4.6	7.0 (5.0)	25 ± 19	65 ± 21
Overall mean	3.5 (0.8)	5.7 (1.2)	22	47

NOTE: Standard deviations are in parentheses
** Data from Morris and Ingram (1993), Morris (1995).*

Penetration results showed that 2nd juvenile wood in this study was considerably more treatable than the old-growth hemlock treated in the 1993 study. Slow/medium grown hemlock met the AWPA standard and fast grown was very close with 73% meeting the standard (Table 6-2), whereas the 1993 study only had a mean of 22% of samples meeting the standard (Table 6-5).

Unincised, 2nd juvenile second-growth hemlock, fast or slow/medium grown, met the CSA decking standard for penetration (Table 6-2). Unincised old-growth hemlock from the 1993 study only achieved a mean of 47% of samples meeting the standard (Table 6-5) for penetration.

5 Conclusions

- In terms of retention, fast grown hemlock from PH580 was more treatable than slow/medium grown hemlock from PH930 and 2nd juvenile wood was more treatable than 1st juvenile wood with both CCA and Acypetacs Copper.
- With respect to mean penetration and percent compliance with penetration requirements in standards for CCA treatment, PH580 fast grown hemlock was shown to be significantly more treatable than PH930 slow/medium grown hemlock. There were no significant differences between 1st and 2nd juvenile wood.
- Acypetacs Copper showed no significant differences between fast (PH580) and slow/medium grown (PH930) hemlock. With fast grown hemlock, 2nd juvenile wood was shown to be more treatable than 1st juvenile wood.
- Full cell treatment of this 2nd juvenile second-growth hemlock with CCA achieved the penetration requirement for decking lumber in CSA 080.32.
- Double vacuum treatment of this second-growth hemlock with Acypetacs Copper achieved the target penetration for the protection of joinery-grade lumber.
- Second-growth hemlock from this work was much more treatable with CCA than the old-growth hemlock in the 1993 study.

6 References

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slow/medium grown and higher retentions for 2nd juvenile than for 1st juvenile. Fast-grown 2nd juvenile wood had the highest retention.

Acypetacs Copper

Treatment results for the Acypetacs Copper treated material (Table 6-3) showed higher retention for fast grown hemlock than for slow/medium grown and higher retentions for 2nd juvenile than for 1st juvenile. Fast-grown 2nd juvenile wood had the highest retention.

Compliance with AWPA and CSA Standards – CCA

In the AWPA C2-98 and CSA O80.2 standards, the penetration requirement for hem-fir is for 80% of the borings to have equal or greater than 10 mm penetration. The retention requirement is 6.4 kg/m³ for ground contact and 4.0 kg/m³ for above-ground contact. These standards require incising of western hemlock.

Not surprisingly, only 2nd juvenile slow/medium grown hemlock met the AWPA C2-98 standard for penetration and retention unincised (Table 6-2). Fast grown 2nd juvenile hemlock had 73% of samples make the requirement. All groups met the ground contact retention requirement.

The CSA O80.32-97 decking standard requires 80% of borings to have equal to or greater than 5 mm penetration. Both fast and slow/medium 2nd juvenile hemlock met this standard and 1st juvenile fast grown hemlock came very close, having 73% of the samples equal to or greater than 5 mm penetration (Table 6-2). The retention requirement in CSA O80.32-97 is 6.4 kg/m³ in a 5 mm assay zone for CCA. Based on the penetration depths measured and the retention in the 16 mm assay zone, all of the groups treated would have met this retention requirement.

Table 6-3 *Results for Second-growth Hemlock Treated with Acypetacs Copper – Core Borings*

Growth Rate	Juvenile	Retention (kg/m³)	Penetration	
			Mean (mm)	% ≥ 3 mm
Slow/Medium	1st	0.70	4.0(4.2)	62
Slow/Medium	2nd	1.00	4.2(2.3)	80
Fast	1st	0.84	4.1(2.8)	59
Fast	2nd	1.58	6.0(4.5)	70

NOTE: Standard deviations are in parentheses

Comparison to 1993 Study of CCA-Treated Old-growth Hemlock

A hem-fir treatability study was carried out at Forintek in 1993 (Morris and Ingram 1993, Morris 1995). In this study hemlock from five coastal sawmills, incised and unincised, was treated with CCA using 3 and 6 hour press times. One set of sub-samples in the present study were prepared and treated as far as possible using identical procedures to one of the groups in the 1993 study: unincised and 6 hour press time. Forintek's wood preservation pilot plant has undergone a series of major upgrades in the intervening six years thus the two sets of work were done using quite different equipment. Nevertheless, since old-growth material from a similar growing site was not available for the present study, it is instructive to compare the results from the second-growth in the present study to the old growth in the 1993 study.

A CCA solution strength of 2.5% was used for both studies and the retention levels from the 1999 study (Table 6-2) were considerably higher than the 1993 study (Table 6-5). Even the most poorly treated, 1st juvenile slow/medium grown hemlock, had almost three times the retention. Considering the difficulty in improving preservative penetration using the full-cell process by adjusting process parameters, it is highly unlikely that this difference could be attributable to upgrades in the equipment.

Table 6-4 *Results for Second-growth Hemlock Treated with Acypetacs Copper – Cross Sections*

Growth Rate	Juvenile	Penetration Mean			C.H.F.* % ≥ 3 mm
		C.H.F.* (mm)	Minimum (mm)	Maximum (mm)	
Slow/Medium	1st	4.9(2.8)	2.3(1.4)	14.3(3.5)	85
Slow/Medium	2nd	5.3(1.6)	2.6(1.5)	16.7(3.5)	90
Fast	1st	6.3(3.5)	3.1(2.0)	12.7(4.9)	86
Fast	2nd	5.9(3.4)	2.9(1.5)	13.8(4.4)	90

** - Centre heartwood face   NOTE: Standard deviations are in parentheses*

Table 6-5 *1993 Study* - CCA*

Mill	Retention kg/m^3	Penetration/Mean		
		(mm)	% ≥ 10 mm	% ≥ 5 mm
A	4.0	6.4 (5.9)	30 ± 20	50 ± 22
	2.6	3.8 (3.1)	5 ± 11	35 ± 21
B	3.6	6.0 (4.9)	20 ± 18	55 ± 22
	3.6	5.9 (4.7)	30 ± 20	40 ± 21
C	3.9	5.9 (4.2)	15 ± 15	55 ± 22
	2.5	4.7 (4.4)	5 ± 11	40 ± 21
D	3.1	6.1 (5.8)	30 ± 20	40 ± 21
	2.8	3.8 (4.5)	10 ± 13	25 ± 19
E	4.7	7.3 (4.9)	45 ± 22	60 ± 21
	4.6	7.0 (5.0)	25 ± 19	65 ± 21
Overall mean	3.5 (0.8)	5.7 (1.2)	22	47

NOTE: Standard deviations are in parentheses

** Data from Morris and Ingram (1993), Morris (1995).*

Penetration results showed that 2nd juvenile wood in this study was considerably more treatable than the old-growth hemlock treated in the 1993 study. Slow/medium grown hemlock met the AWPA standard and fast grown was very close with 73% meeting the standard (Table 6-2), whereas the 1993 study only had a mean of 22% of samples meeting the standard (Table 6-5).

Unincised, 2nd juvenile second-growth hemlock, fast or slow/medium grown, met the CSA decking standard for penetration (Table 6-2). Unincised old-growth hemlock from the 1993 study only achieved a mean of 47% of samples meeting the standard (Table 6-5) for penetration.

5 Conclusions

- In terms of retention, fast grown hemlock from PH580 was more treatable than slow/medium grown hemlock from PH930 and 2nd juvenile wood was more treatable than 1st juvenile wood with both CCA and Acypetacs Copper.
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SECTION

7

MACHINING PROPERTIES

Derek Williams

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SECTION

7

MACHINING PROPERTIES

1 Introduction

This study examined the machining properties of second-growth coastal western hemlock from known age class, growing conditions and growth rates. Comparisons were made between two second-growth western hemlock growing sites on Vancouver Island, British Columbia: one with a high stand density and comparatively high wood density (PH930), and the other with a lower stand density and comparatively low wood density (PH580).

The machining operations performed were those encountered in commercial secondary wood-processing plants and included planing, sanding, shaping, boring, mortising and turning. A recently completed similar study, *Machining and Related Mechanical Properties of 15 B.C. Wood Species* [3], included B.C. coastal old-growth western hemlock. Data from that study were used to compare the machining properties of second-growth western hemlock to those of old growth.

2 Methods

Sample Selection and Preparation

Machinability comparisons were made within and between each stand density class with respect to the following samples:

- 100% juvenile wood,
- 50% juvenile wood / 50% mature wood, and
- 100% mature wood.

The low stand density sample (PH580) material was further sub-divided by log size: logs with breast-height diameter of 40 cm. and less, and those from trees with breast-height diameter of 55 cm. or more. A total of nine sample sorts were made. Table 7-1 provides a summary of sample sizes by category.

The lumber selected for the machining tests was obtained from pieces used in other tests or unused lumber. Each piece of lumber was first selected by stand of origin: PH930 or PH580. The ends of each piece were next evaluated to determine juvenile wood proportion as indicated by a previous coding system of paint and coloured line. Lumber selected was marked to indicate the location of sample cuttings. Thick stock, such as 105 x 105 mm, was resawn to give a 36 mm thick board on the best face from which the cuttings were obtained. An effort was made to obtain as many lumber pieces from as many different trees as possible though it became necessary to use lumber from the same tree in different sorts.

Wood density values were available for the lumber used in the machining tests. Average density values for test categories are appended. The average density for PH930 (the slow grown site) was slightly higher than that for PH580 (the fast grown site) or 0.46 and 0.44 respectively. This result was as expected. A larger difference was observed for the juvenile wood from each site, 0.45 and 0.42 from PH930 and PH580 respectively. This trend was also repeated in the difference between density values for the mature wood from each site, 0.53 and 0.47 for PH930 and PH580 respectively. However, for the 50/50 mix of juvenile and mature wood samples the slower grown stand had lower density than the faster grown stand, 0.44 and 0.46 for PH930 and PH580 respectively. The small sample size could explain this discrepancy.

Each cutting was stamped with a four-digit number for identification; then the board was sawn into cuttings. A total of six cuttings were made from each board as follows:

- 1 - 36x4 inch cutting used in the planing and sanding tests,
- 1 - 12x3 inch cutting used in the shaping, boring and mortising test,

Table 7-1 *Lumber Sample Distribution by Categories*

PH930		PH580	
Category	**No. of Pieces**	**Category**	**No. of Pieces**
100 % Juvenile	37	100% Juvenile ≥55 cm.	21
		100% Juvenile ≤40 cm.	32
50% Juv./50% Mat.	21	50% Juv./50% Mat. ≥55 cm.	17
		50% Juv./50% Mat. ≤40 cm.	7
100% Mature	27	100% Mature ≥55 cm.	20
		100% Mature ≤40 cm.	22
Totals	85		119

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Totals	85		119

- 1 - 6x1.5 inch cutting for the turning test.
- 2 - 6x2 inch cuttings for the fastener withdrawal tests.
- 1 - small section to determine density and number of rings per inch.

The cuttings were conditioned to between 11 and 12 percent moisture content. Samples were kept in the conditioning chamber until a machining test was ready to commence.

Though the testing procedure calls for clear-wood cuttings, a decision was made to include tight knots in the planing and sanding test cuttings. This would better reflect the true machining properties of second-growth western hemlock. Knots were present in the shaping cuttings but they were not in the areas where the machining was performed. The turning cuttings for all the samples were clear wood pieces as knots create a weak area where the piece could fracture during the turning process.

Wood Machining Tests

The machining tests were conducted according to American Society for Testing and Materials (ASTM) D 1666-87: *Standard Methods for Conducting Machining Tests of Wood and Wood-Based Materials*. However, some settings were modified in the interest of obtaining the best possible surface quality. These modifications are discussed under "Procedure" for each test.

The tests require evaluation of the surface quality produced by the machining operations. This was done both visually and by touch. The ASTM D1666 standard uses five quality grades based on the amount and severity of defect present, as follows:

- Grade 1 — excellent / defect free
- Grade 2 — good
- Grade 3 — fair
- Grade 4 — poor
- Grade 5 — very poor.

Table 7-2 lists each machining test and the quality grades used in determining overall performance.

The practice of using different grades or combination of grades for each test may appear to be inconsistent. However, the grade combinations are those that are considered suitable for most purposes found in secondary wood processing. Samples of each grade and type of defect were kept for reference.

Table 7-2 *Quality Grades Used in Determining Performance for each Machining Test*

Machining Test	Performance Criteria
Planing	Grade 1
Sanding	Grade 1
Shaping	Grades 1 and 2
Boring	Grades 1 and 2
Mortising	Grades 1, 2 and 3
Turning	Grades 1 and 2

Table 7-3 *Comparison of Knife Marks per Inch (KMPI) by End Use*

Product	KMPI
Lumber for Construction	4 to 8
Exterior Wood Products	8 to 12
Millwork	12 to 16
Furniture	16 to 20

The number of knife marks per inch (KMPI) is often used as a measure of surface quality in planing. It is determined by the feed speed, spindle rpm and number of knives making the final cut. As the latter two parameters were not varied during the tests, altering the feed speed was the only way of changing the number of knife marks per inch. Table 7-3 shows the number of knife marks per inch typically found in various wood products.

Planing

Definition

Planing is second to sawing as the most important machining operation in a wood processing plant. Lumber has to be dressed to size and/or surfaced prior to further use. Accordingly, this study placed more emphasis on the planing test than on the other machining tests. Planing provides an excellent opportunity for adding value to a product. This machining process can be performed by a planer or moulder.

Equipment

The planing test was conducted on a Wadkin through-feed moulder with five spindles. Only the top spindle was used in the planing tests. The machine had a variable feed rate with a spindle rotation speed of 6000 rpm.

A hydraulically clamped cutter head with a 20° hook angle was used. The knife stock used was industry standard high-speed steel (HSS) of the M-3 grade with corrugated back. Actual knives were cut from individual bar stock and balanced to within 0.2 grams to run without vibration. Each knife was carefully ground using an aluminium-oxide wheel to a consistent cutting circle on a profile grinder. The knives were ground to a keen edge through several lapping passes.

Procedure

Four passes were made with each sample using a 0.1 inch (2.5 mm) depth of cut under different sets of conditions. The four runs were set at various feed speeds to yield 20, 16, 12 and 8 knife marks per inch as seen on the surface of the planed wood samples. The number of knife marks per inch was determined by running a few test pieces through the moulder, and adjusting the feed rate until the desired

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Samples were graded for the presence of fuzzy grain, raised grain, torn grain and chip marks. The presence and severity of raised and fuzzy grain was determined by touch.

Sanding

Definition

Sanding is a method of preparing the wood surface for the application of a finish coating (e.g., sealer, stain, oil, and lacquer). Sanding wood properly is the first step in applying a first class finish. Mistakes made in sanding often show up after the finish is applied.

Sanding is an abrasive action that leaves a scratch pattern on the wood surface, and is directly influenced by the grit size of the sandpaper. To remove excessive scratch patterns, progressively finer grit sandpaper is used until the desired surface smoothness is reached.

Equipment

This test was conducted on a Cemco wide belt sander mounted with two successive sanding heads. The belt sequence was an 80 grit, cloth-backed aluminum oxide belt on the first head and a 120 grit, cloth-backed aluminum oxide belt on the second head. The feed rate was adjusted to 20 ft/min (6.1 m/min).

Procedure

The planing samples were used for the sanding tests. They were not cut down to a 12 inch length as recommended in the ASTM standard but left in the 3 foot length. In order to use the whole width of the belt, the sanding specimens were staggered across the belt. The sanding test run was made just after the planer run that produced 16 KMPI.

Shaping

Definition

Shaping is similar to planing with respect to cutting action and type of tooling. The major difference is the shaper's ability to profile curved pieces of wood, whereas the planer can only profile straight lumber. A shaper is a versatile machine and can produce a variety of cuts (grooves, rebates, profiles, dados, etc.).

Equipment

The shaping test was conducted on a SCM T120C single spindle shaper operated at a spindle speed of 7200 rpm. The tooling used was a six pocket (wing) cutter head with removable HSS knives though only three of the pockets contained a knife (this was a specially ordered cutter head with three 10° and three 20° pocket angles). Each pocket in the cutter head was numbered, as were the knives and corresponding gibs. The 20° pockets were used for shaping softwoods. The knives were recently sharpened by the tooling manufacturer, and the profile was the same as shown in the ASTM standard.

A jig was designed to hold the sample in place while shaping. The jig was similar to that described in the ASTM standard, with the addition of toggle clamps to help secure the workpiece. The workpiece was fed by guiding the jig against a bearing mounted underneath the cutter head. This set-up produced duplicate curved patterns with every pass.

Procedure

Prior to being shaped, each sample was bandsawn to a pattern using a template. Two passes were made on the shaper: a preliminary pass that removed a lot of material followed by a second pass that removed the required 1/16 inch (1.6 mm) of material. This was accomplished by placing a 1/16 inch strip of veneer between the sample and the jig's base. All the cutting action was against the grain as is the usual way of operating a shaper safely.

All samples were examined visually and by touch. Samples were graded for the presence of fuzzy grain, raised grain, torn grain and end grain tear out. As in the evaluation of planing pieces, the sense of touch was found to be a more efficient method of determining the presence and severity of raised and fuzzy grain.

Boring

Definition

Boring, like shaping, is performed extensively in furniture and other woodworking plants. Boring holes into wood can serve two purposes: 1) to receive dowels and 2) to pre-drill "pilot" holes for insertion of screws or other type of fastener. The bored hole must be round without any noticeable distortion and have an inner surface conducive to good glue bonding (free of torn and crushed grain). Dowels serve to: 1) reinforce the joint, and 2) accurately position adjacent parts, thereby allowing fast assembly. Boring is extensively used in the manufacture of RTA (Ready to Assemble) furniture.

Equipment

The boring machine used was an Ashina bench drill press with a 1/2 hp motor. The feed rate was approximately 1 inch in 6 seconds. The bit used was a brad and lip point bit (often referred to as a brad bit) though the ASTM standard recommended a single twist, solid-centre point bit. The former bit was used because it is more modern and is now in general use throughout industry. In similar boring tests previously conducted by the author, the brad bit performed considerably better than the single twist bit. The brad point bit differs from the single twist bit in that it has two flutes (twists) instead of one, and two lips ground into the ends of its flutes. The lips in the brad point bit act as spurs severing wood fibres before they are removed thus producing a more accurate and clean hole.

Procedure

Adaptations to the ASTM recommended test procedure were necessary, since the recommended spindle speed of 3600 rpm was found to cause burning of the wood and overheating of the boring bit. After a number of trials, a spindle speed of 1200 rpm was found to be satisfactory. The boring tests were conducted after the shaping test using the same samples.

The brad point bit was used to bore one hole into each of the wood samples. A jig was made so that the holes were placed in approximately the same location for each specimen (hole position was changed if knots were too close). A removable wooden baseboard was used under the test pieces, which was replaced when worn.

All samples were examined with the aid of a magnifying glass. The bored holes were graded for the presence of crushed, fuzzy, or torn grain, and general smoothness of cut.

Mortising

Definition

The mortise and tenon joint is common in furniture making and in window and door joinery. The tenon is a square or rectangular projection on the end of a part and the mortise is a corresponding hole into which the tenon is inserted (with optional glue) to form a very strong joint. The mortise and tenon joint serves two functions:

- It creates a strong joint by the interlocking of adjoining parts; if the mating parts are machined accurately and properly glued, the joint can only fail by breaking off the tenon.
- The mortise acts as a precise locator — the mating tenon can only fit in a predetermined location.

Equipment

There are three basic types of mortisers used in the wood industry: hollow chisel, oscillating chisel and chain. Though the ASTM standard prescribed the use of only the hollow chisel mortiser, inquiries made with the joinery industry revealed that most companies prefer the chain type mortiser. The chain mortiser resembles a chain saw. Small teeth, set on a chain, continuously rotate around two sprockets. The result is an elongated rectangular hole, and the mortises can be varied in size by using a different chain. We decided to use it to more accurately reflect current industry practice.

The chain mortiser used was equipped to produce a 3-3/4 by 1/2 inch (95 by 12.7 mm) rectangular mortise. The cutting pressure was hydraulically actuated.

Procedure

One hole was machined in the centre point of the test piece near the square end. Being an elongated hole the long axis was parallel to the grain, as in typical joinery applications.

Each mortise hole was evaluated for the presence of crushing, tearing, and splintering of the grain and for the general smoothness of the cut. Splintering was evaluated at the location where the mortiser exited the workpiece.

Turning

Definition

Turning is one of the key value-added processes performed by the secondary wood processing industry.

Equipment

The ASTM standard recommended the turning test be performed with a back knife. Contacts with local wood turning plants revealed that the back knife type of lathe was not as common as the rotary-knife (shaping) lathe for softwoods. Therefore, to reflect current general woodworking practices, the rotary-knife lathe was tested.

A Matison type lathe was used to perform the turning tests. The rotational speed of the *knife assembly* for the rotary-knife lathe was 3000 rpm.

Procedure

The turning profile referenced in the ASTM standard was not replicated. Instead, a section from a standard spindle profile was selected, since the knife set-up was already available. High labour costs associated with tool and machine set-up on the rotary-knife lathe discouraged the use of producing a new pattern.

The lathe was a hopper fed machine in which the turning blocks are automatically fed into the machine and ejected once the turning is completed. On account of the machining process being done to the complete outside surface of the turning block each block had to be renumbered on both ends. Turning samples were evaluated for the presence of torn grain, fuzzy grain and rough end grain.

3 Results and Discussion

Wood Machining Tests

Table 7-4 provides a summary of machining results for the two test samples. Included in the table are machining results obtained from similar tests of old-growth western hemlock. British Columbia wood producers and their customers are familiar with the machining properties of old-growth western hemlock, but second-growth hemlock is much less prevalent and this study provides the first comparative evaluation. The two studies were made a number of years apart but every effort was made to repeat the subjective criteria used to judge the characteristics of the machined surfaces. A more reliable comparison would be obtained from concurrent tests of old-growth and second-growth western hemlock wood.

Table 7-5 provides machining results obtained for wood from each sample location divided into the three juvenile-mature wood classes.

Table 7-4 *Machining Results Compared by Stand and with Old-growth Data*

Test	PH580		PH930		Old Growth	
	Defect Free %	Good to Defect Free %	Defect Free%	Good to Defect Free %	Defect Free %	Good to Defect Free%
Planing	47	97	56	97	48	99
Sanding	84	100	83	100	96	96
Shaping	54	96	55	98	32	76
Boring	71	94	79	96	86	86
Mortising	62	73 (91)	63	89 (98)	78	86 (89)
Turning	30	89	32	92		47

For mortising ( ) = cumulative percentage fair to defect free

Table 7-5 *Machining Results Compared by Wood Sample and Juvenile Wood Classes*

Test	PH580						PH930					
	Juvenile		Juv. / Mat.		Mature		Juvenile		Juv. / Mat.		Mature	
	Defect Free %	Good to Defect Free %	Defect Free %	Good to Defect Free %	Defect Free%	Good to Defect Free %	Defect Free %	Good to Defect Free %	Defect Free %	Good to Defect Free %	Defect Free %	Good to Defect Free %
Planing	46	100	52	95	42	100	56	97	49	100	63	100
Sanding	78	100	79	100	94	100	90	100	79	100	79	100
Shaping	60	98	40	95	59	97	66	100	44	94	56	100
Boring	63	87	66	97	85	98	66	88	78	100	94	100
Mortising	67	77 (90)	67	72 (91)	53	71 (89)	66	88 (100)	56	84 (95)	67	95 (99)
Turning	20	82	42	95	27	91	39	94	32	90	24	91

For mortising ( ) = cumulative percentage fair to defect free

Table 7-6 provides the machining results obtained from the PH580 sample divided into the two tree size classes.

Table 7-7 provides a further breakdown of the PH580 tree size comparisons further divided into the three juvenile wood classes.

Planing

Experience gained in performing similar planing tests, has shown that one defect in particular, fuzzy grain, occurs at a grade 2 level (which is considered slight) in many of the samples. Experience has also shown that a high proportion of the slight fuzzy grain is cleaned up or removed after sanding. Therefore it was considered worthwhile to include samples that exhibited fuzzy grain at the grade 2 level of severity ('good' grade) as well as the defect-free samples in the analysis of the planing performance of second growth hemlock. Many products or components used in value-added production are sanded to improve the surface appearance and smoothness of the wood.

The planing results in Table 7-4 are the average of all four runs. It can be seen that in terms of defect-free samples PH930 outperformed PH580 indicating that higher density fibre on average produces better quality planed lumber than lower density fibre within the same species. With regard to the good to defect-free performance where fuzzy grain grade level 2 is allowed, the test samples approached 100% acceptable. This indicates that second-growth hemlock is prone to have slight fuzzy grain in about half of the lumber pieces run through a moulder. Overall the PH930 samples did slightly better than the old growth samples with PH580 samples being virtually the same as the old growth.

Table 7-6 *Machining Results from PH580 Compared by Tree Size Class*

Test	Trees ≤ 40 cm D.b.h.		Trees ≥ 55 cm D.b.h.	
	Defect Free%	Good to Defect Free %	Defect Free%	Good to Defect Free%
Planing	45	96	45	95
Sanding	76	100	90	100
Shaping	48	91	59	97
Boring	78	97	61	90
Mortising	58	71 (88)	65	86 (95)
Turning	38	87	27	92

For mortising ( ) = cumulative percentage fair to defect free

Table 7-4 *Machining Results Compared by Stand and with Old-growth Data*

Test	PH580		PH930		Old Growth	
	Defect Free %	Good to Defect Free %	Defect Free%	Good to Defect Free %	Defect Free %	Good to Defect Free%
Planing	47	97	56	97	48	99
Sanding	84	100	83	100	96	96
Shaping	54	96	55	98	32	76
Boring	71	94	79	96	86	86
Mortising	62	73 (91)	63	89 (98)	78	86 (89)
Turning	30	89	32	92		47

For mortising ( ) = cumulative percentage fair to defect free

Table 7-5 *Machining Results Compared by Wood Sample and Juvenile Wood Classes*

Test	PH580						PH930					
	Juvenile		Juv. / Mat.		Mature		Juvenile		Juv. / Mat.		Mature	
	Defect Free %	Good to Defect Free %	Defect Free %	Good to Defect Free %	Defect Free%	Good to Defect Free %	Defect Free %	Good to Defect Free %	Defect Free %	Good to Defect Free %	Defect Free %	Good to Defect Free %
Planing	46	100	52	95	42	100	56	97	49	100	63	100
Sanding	78	100	79	100	94	100	90	100	79	100	79	100
Shaping	60	98	40	95	59	97	66	100	44	94	56	100
Boring	63	87	66	97	85	98	66	88	78	100	94	100
Mortising	67	77 (90)	67	72 (91)	53	71 (89)	66	88 (100)	56	84 (95)	67	95 (99)
Turning	20	82	42	95	27	91	39	94	32	90	24	91

For mortising ( ) = cumulative percentage fair to defect free

Table 7-6 provides the machining results obtained from the PH580 sample divided into the two tree size classes.

Table 7-7 provides a further breakdown of the PH580 tree size comparisons further divided into the three juvenile wood classes.

Planing

Experience gained in performing similar planing tests, has shown that one defect in particular, fuzzy grain, occurs at a grade 2 level (which is considered slight) in many of the samples. Experience has also shown that a high proportion of the slight fuzzy grain is cleaned up or removed after sanding. Therefore it was considered worthwhile to include samples that exhibited fuzzy grain at the grade 2 level of severity ('good' grade) as well as the defect-free samples in the analysis of the planing performance of second growth hemlock. Many products or components used in value-added production are sanded to improve the surface appearance and smoothness of the wood.

The planing results in Table 7-4 are the average of all four runs. It can be seen that in terms of defect-free samples PH930 outperformed PH580 indicating that higher density fibre on average produces better quality planed lumber than lower density fibre within the same species. With regard to the good to defect-free performance where fuzzy grain grade level 2 is allowed, the test samples approached 100% acceptable. This indicates that second-growth hemlock is prone to have slight fuzzy grain in about half of the lumber pieces run through a moulder. Overall the PH930 samples did slightly better than the old growth samples with PH580 samples being virtually the same as the old growth.

.Table 7-6 *Machining Results from PH580 Compared by Tree Size Class*

Test	Trees ≤ 40 cm D.b.h.		Trees ≥ 55 cm D.b.h.	
	Defect Free%	Good to Defect Free %	Defect Free%	Good to Defect Free%
Planing	45	96	45	95
Sanding	76	100	90	100
Shaping	48	91	59	97
Boring	78	97	61	90
Mortising	58	71 (88)	65	86 (95)
Turning	38	87	27	92

For mortising ( ) = cumulative percentage fair to defect free

Table 7-7 *Machining Results from PH580 Compared by Tree Size and Juvenile Wood Classes*

Test	Trees ≤ 40 cm D.b.h.						Trees ≥ 55 cm D.b.h.					
	Juvenile		Juv. / Mat.		Mature		Juvenile		Juv. / Mat.		Mature	
	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)
Planing	46	100	43	100	44	100	43	100	52	88	38	99
Sanding	72	100	71	100	86	100	86	100	83	100	100	100
Shaping	52	93	29	86	64	93	75	100	46	92	55	100
Boring	62	90	86	100	86	100	62	86	33	91	84	95
Mortising	59	70 (85)	71	85 (99)	50	57 (86)	76	86 (96)	33	91 (99)	55	80 (90)
Turning	14	76	71	100	29	86	29	91	25	92	26	94

For mortising ( ) = cumulative percentage fair to defect free

Figure 7-1
Effects of Knife Marks per Inch on Planing Performance

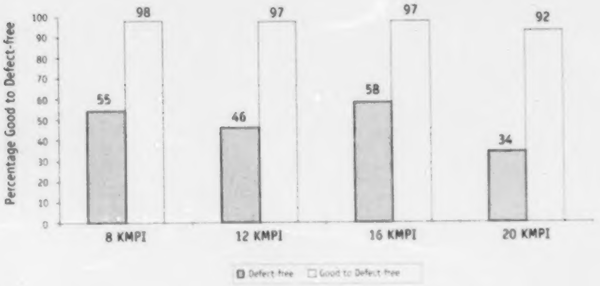


Figure 7-2
Comparative Planing Performance Using KMPI

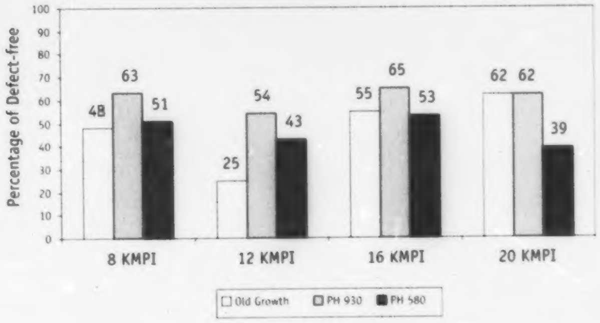
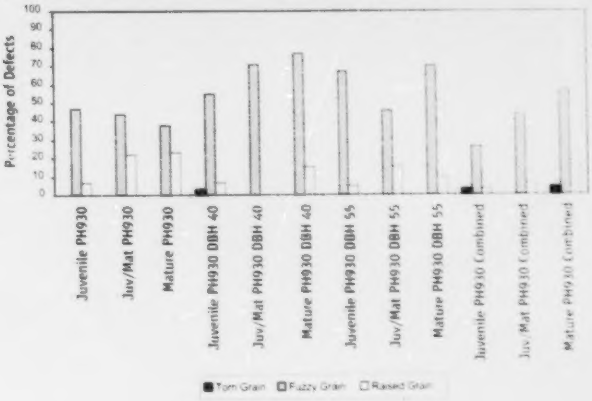


Figure 7-3
Planing Defects by Frequency of Occurrence



The comparison of results by juvenile wood class in Table 7-5 shows that for PH930 the mature wood samples were 63%defect-free whereas samples with juvenile wood present had slightly lower percentages of defect-free. For PH580 the mature wood samples did not surpass the performance of those with juvenile wood present.

The comparative overall performance by tree size class for PH580 shown in Table 7-6 reveals no difference between the larger and smaller tree diameter classes. The further breakdown by juvenile wood class in Table 7-7 shows that with this lower density PH580 fibre there was little difference in percentage of defect-free samples regardless of tree size or juvenile wood content.

Figure 7-1 shows in general the effects of knife marks per inch on the number of defect-free pieces produced. Normally, as the number of knife marks increases the surface becomes smoother, however, with second-growth hemlock the best result was obtained with 16 KMPI, followed closely by 8 KMPI. Runs made at 20 KMPI had the lowest percentage of defect-free samples. Figure 7-2 compares planing performance in terms of KMPI for the second-growth samples with results from the previous tests of old growth. In the tests of old-growth hemlock the best results were obtained in the 20 KMPI run.

This same effect was observed with old-growth hemlock. The implication for finish quality versus feed speed is that running a moulder at a the slowest feed speed will not necessarily produce a finer surface, but it will lower output. For second-growth hemlock the optimal feed speed is one

Table 7-7 *Machining Results from PH580 Compared by Tree Size and Juvenile Wood Classes*

Test	Trees ≤ 40 cm D.b.h.						Trees ≥ 55 cm D.b.h.					
	Juvenile		Juv. / Mat.		Mature		Juvenile		Juv. / Mat.		Mature	
	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)	Defect Free(%)	Good to Defect Free(%)
Planing	46	100	43	100	44	100	43	100	52	88	38	99
Sanding	72	100	71	100	86	100	86	100	83	100	100	100
Shaping	52	93	29	86	64	93	75	100	46	92	55	100
Boring	62	90	86	100	86	100	62	86	33	91	84	95
Mortising	59	70 (85)	71	85 (99)	50	57 (86)	76	86 (96)	33	91 (99)	55	80 (90)
Turning	14	76	71	100	29	86	29	91	25	92	26	94

For mortising ( ) = cumulative percentage fair to defect free

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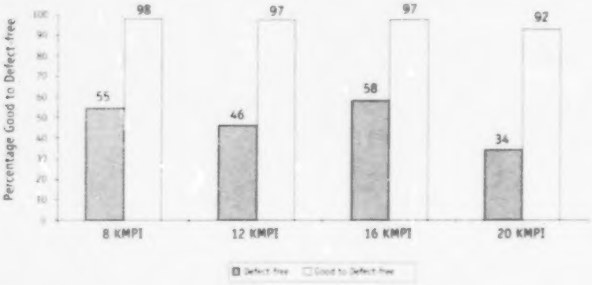

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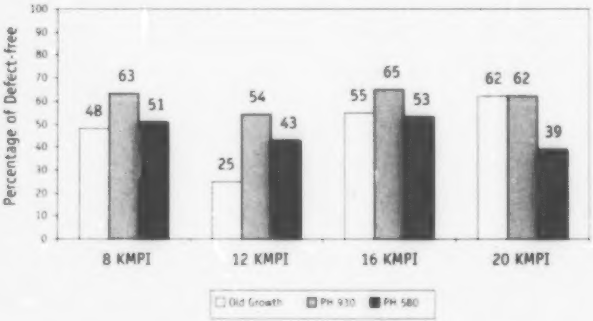

Figure 7-3
Planing Defects by Frequency of Occurrence

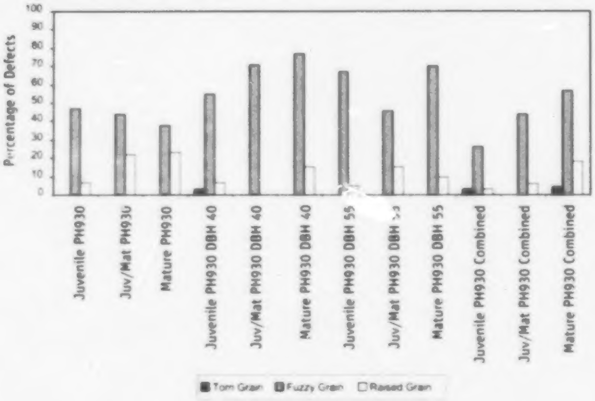

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Figure 7-1 shows in general the effects of knife marks per inch on the number of defect-free pieces produced. Normally, as the number of knife marks increases the surface becomes smoother, however, with second-growth hemlock the best result was obtained with 16 KMPI, followed closely by 8 KMPI. Runs made at 20 KMPI had the lowest percentage of defect-free samples. Figure 7-2 compares planing performance in terms of KMPI for the second-growth samples with results from the previous tests of old growth. In the tests of old-growth hemlock the best results were obtained in the 20 KMPI run.

This same effect was observed with old-growth hemlock. The implication for finish quality versus feed speed is that running a moulder at a the slowest feed speed will not necessarily produce a finer surface, but it will lower output. For second-growth hemlock the optimal feed speed is one that produces 16 KMPI. Anything finer only generates more fuzzy grain.

Figure 7-3 provides a breakdown of planing defects by frequency of occurrence. Fuzzy grain was the most frequently occurring defect in planing. A further test was done to see if samples that were prone to fuzzy grain 2 (and even 3) could be cleaned up after sanding. The test revealed that sanding does indeed remove persistent cases of fuzzy grain. (See sanding results below.) The second most frequent defect was raised grain. Often this occurred in vertical grain samples or in areas of a sample where vertical grain was found. Sometimes raised grain could be removed by sanding if it was not too severe.

Sanding

Comparison of the sanding properties was based on the percentage of defect-free samples for each stand. Between PH930 and PH580 there was no difference in sanding performance. Differences did appear when a detailed breakdown was made. Juvenile wood on PH930 performed considerably better than the mature wood from this site though this trend was just the opposite with PH580 results. Here mature wood outperformed samples containing juvenile wood. The most prevalent defect encountered was fuzzy grain although most of the samples with fuzzy grain prior to sanding had this defect removed by sanding. Upon closer examination of the sanding results it was found that 62% of the samples with planing defects cleaned up after sanding, 9% of the samples remained the same and 29% actually got worse (from having no fuzzy grain to having fuzzy grain albeit of a slight nature). Why this occurred was not understood.

Old growth outperformed second growth by a 10 percent margin in sanding performance though all samples did well.

Shaping

Comparison of the shaping properties was based on the percentage of good to excellent samples present. There was no real difference in outcome when good to defect-free grade was used for performance evaluation.

In the good to defect-free category the two second-growth samples did considerably better than the old-growth data. The second-growth samples were in the high 90 percent range acceptable whereas the old-growth data were in the mid-70 percent range. A similar result was obtained in the defect-free category.

The tests indicated that second-growth western hemlock will give good results in wood processing where shaping is required. When just the defect-free samples were compared, the PH580 trees with dbh ≥55 cm performed best overall. Table 7-7 shows that the 100 percent juvenile wood class accounted for a large part of the higher performance of this diameter class in the defect-free category. Also of interest, when defect-free samples only were considered, was the performance of juvenile wood when compared to mature wood. It was expected that juvenile wood would not perform as well as mature wood, but on average it performed as well or slightly better. The most frequent defect was raised grain, followed by fuzzy grain and rough-end grain.

Boring

The comparison of boring properties was based on the percentage of good to excellent pieces present in each sample. In the good to defect-free performance category, both sites and tree diameter classes had average performances in the 90 percent plus range accepted. When defect-free samples only were considered, a difference in performance emerged. The higher density wood from PH930 performed best. The average performance of the PH580 sample was lowered by the results obtained from the large tree diameter class. As expected, mature wood performed better than juvenile wood. The percent of test pieces that were defect-free increased from juvenile wood to mature wood in all sample classes with the exception of the PH580 dbh ≥55 class (possibly due to the limited sample of twelve pieces).

Table 7-4 shows that the second-growth samples, PH930 and PH580 performed somewhat better than the old growth in the good to defect-free category, but the old growth had somewhat more defect-free samples.

The main cause of defects was crushing of wood fibres against the sidewall of the bore hole and the resulting lack of smoothness of the sidewall. This is a problem when glue is used to secure a dowel to the inside wall of the hole. Crushed fibre does not provide a good, strong, well-anchored substrate for the glue to penetrate, and glue failure can occur.

Mortising

Comparison of the mortising properties was based on the percentage of fair to excellent pieces in each sample, as stipulated in the ASTM standard.

In the fair to defect-free performance category, all sites and tree diameter classes had average performances in the 88 to 98 percent range. When the good to defect-free category was considered, a sizeable difference was found between PH930 and PH580 with the smaller diameter tree size lowering the PH580 average. Defect-free results from all sites were similar, in the 58 to 65 percent range. The more detailed tables show that there was no appreciable difference in mortising performance between sample locations or juvenile wood and mature wood proportions.

Table 7-4 shows that the results for the second-growth samples were just slightly better than the old-growth data in the fair to defect-free category, and the old-growth data were comparatively better in the defect-free category.

Splintering of the grain as the chain emerged from the mortise hole was the most frequent cause of defects. Some of these splinters extended well beyond the area that the shoulder of a tenon joint would be able to cover. Use of a chip breaker to support the fibre on the side of the chain mortise that emerges from the sample could have reduced the severity of the splinters. The feasibility of fitting a chip breaker to chain mortise machines was not determined.

Turning

The comparison of turning properties was based on the percentage of good to excellent pieces in each sample. There was no difference in performance between PH930 and PH580 with regard to turning properties. Based on the good to defect-free grading criteria the average performance for all sites and tree diameter classes was in the 87 to 92 percent range. Overall, mature wood performed somewhat better than juvenile wood in the good to defect-free category. As well, larger diameter trees from PH580 performed better on average than the smaller diameter trees.

The defects that occurred most often were torn grain and rough end grain. The torn grain was of a slight category which could be easily sanded out (most turned wood products are sanded on a specialized machine sander). The rough end grain, of the slight category, was deemed to be repairable with little effort. There was some raised grain and some fuzzy grain but it was not very prevalent. Of note were the large differences between the percentages of defect-free pieces and good to defect-free pieces. In no other test was the difference so great.

Table 7-4 shows a very large difference between turning results obtained for second growth and the turning performance data for old growth. This large difference could be the result of subjectivity in judging defects. Turned wood products are important for the secondary wood processing industry and the comparative turning performance of old growth and second growth should be further evaluated.

4 Conclusions

The machining tests demonstrated that there was no appreciable difference between the coastal second-growth western hemlock obtained from PH930 versus PH580. There was also no consistent difference in performance between juvenile wood and mature wood although mature wood samples did slightly outperform juvenile wood samples in most tests.

The more surprising results came from the comparison of the second-growth western hemlock with old-growth western hemlock. In many of the tests, second growth machined as well as, or better than, old growth.

5 References

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Appendix

Density

Category Averages

Category	PH930 Juvenile	PH930 Juv/Mat	PH930 Mature	PH580 Juvenile dbh ≤40	PH580 Juv/Mat dbh ≤40	PH580 Mature dbh ≤40	PH580 Juvenile dbh ≥55	PH580 Juv/Mat dbh ≥55	PH580 Mature dbh ≥55
Average	0.4508	0.4382	0.5333	0.4169	0.4539	0.4836	0.4313	0.4573	0.4469

Category	PH930 Overall	PH580 Overall	PH580 ≤40 Overall	PH580 ≥55 Overall
Average	0.4560	0.4383	0.4355	0.4413

SECTION

8

THE PULPING PROPERTIES OF SECOND-GROWTH WESTERN HEMLOCK

P.A. Watson, W. Gee, S.S. Johal,
S.M. Beath, B.K. Yuen and A. Hussein

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Figure 8-3
Age vs Fibre Coarseness (mg/m) for Second-growth Western Hemlock

Figure 8-4
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Figure 8-5
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Figure 8-7
PFI Revolutions vs Tensile Index for PH930 Juvenile, Mature and Top Wood Kappa 30 Kraft Pulps

Figure 8-8
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Figure 8-10
Tensile Index vs Tear Index for PH930 Juvenile, Mature and Top Wood Second-growth Kappa 30 Western Hemlock Kraft Pulps

Figure 8-11
Tensile Index vs Tear Index for Second-growth Kappa 30 Western Hemlock Mature Wood Kraft Pulps

Figure 8-12
PFI Revolutions vs Sheffield Smoothness for PH930 Juvenile, Mature and Top Wood Kappa 30 Second-growth Western Hemlock Kraft Pulps

Figure 8-13
PFI Revolutions vs Sheffield Smoothness for Kappa 30 Second-growth Western Hemlock Mature Wood Kraft Pulps

Figure 8-14
PFI Revolutions vs Tensile Index for Western Hemlock Mature Wood and Radiata Pine Sawmill Chip Samples

Figure 8-15
Apparent Density vs Tensile Index for Western Hemlock Mature Wood and Radiata Pine Sawmill Chip Samples

Figure 8-16
Tensile Index vs Tear Index for Western Hemlock Mature Wood and Radiata Pine Sawmill Chip Samples

Figure 8-17
Specific Energy vs Unscreened Freeness for PH930 Second Growth Western Hemlock Juvenile, Mature and Top Wood Thermomechanical Pulps

Figure 8-18
Specific Refining Energy vs Unscreened Freeness for Western Hemlock Mature Wood Thermomechanical Pulps

Figure 8-19
Screened Freeness vs Tensile Index for PH930 Second-growth Western Hemlock Juvenile Mature and Top Wood Thermomechanical Pulps

Figure 8-20
Screened Freeness vs Tensile Index for Western Hemlock Mature Wood Thermomechanical Pulps

Figure 8-21
Screened Freeness vs Tear Index for Western Hemlock Mature Wood Thermomechanical Pulps

Figure 8-22
Weight Weighted Average Fibre Length vs Tear Index for Western Hemlock Mature Wood Thermomechanical Pulps

THE PULPING PROPERTIES OF SECOND-GROWTH WESTERN HEMLOCK

SECTION

8

1 Introduction

Western hemlock (*Tsuga heterophylla* (Raf.) Sarg) grows throughout the Coastal, Columbia and Subalpine forest regions of British Columbia and is an extremely valuable source of both sawn lumber and pulpwood [1]. The large volumes of available coastal western hemlock [2] and the significantly improved growth rates of second-growth material [3] ensure that western hemlock will remain one of the mainstays of the coastal resource. However, for coastal pulp and papermakers western hemlock is regarded as perhaps the least desirable of the coastal species. It has inherently low brightness which requires expensive bleaching chemicals to achieve pulp brightness levels suitable for wood-containing grades. In addition, western hemlock kraft pulp is widely accepted as the true BC commodity pulp with properties generally believed to be similar to fast grown radiata pine, which is a significantly cheaper pulp to produce.

However, the characteristics of the coastal western hemlock resource are changing over time from old-growth, to the current situation of increasing levels of decadent wood, as "overmature" stands are harvested and restored to productivity [4], coupled with an increasing emphasis on shorter rotation material.

A number of general pulping studies have been completed on western hemlock from uncharacterized sources [5-9]. Experiments undertaken in this laboratory on western hemlock progeny indicate significant genetic diversity in this species [10]. Wellwood [11] evaluated the specific gravity and tracheid length variations in 60-year-old second-growth western hemlock. He found that whereas site had no effect on tracheid length, a crown class effect was observed whereby stems with large crowns possessed more juvenile wood than those with smaller crowns. This has recently been independently confirmed by Paprican studies undertaken on spaced western hemlock [12]. More recently, Kayahara et. al. [13] have reported that the site index of western hemlock did not reflect the productivity of the site which is perhaps further proof of the genetic diversity within this species.

In this study we have determined the fibre, pulping and pulp properties, from kraft and thermomechanical pulping processes, of second-growth 90-year-old western hemlock obtained from 3 well characterized sites on Vancouver Island. Where possible, these data have been compared with an old-growth sample which was evaluated at the same time.

2 Method

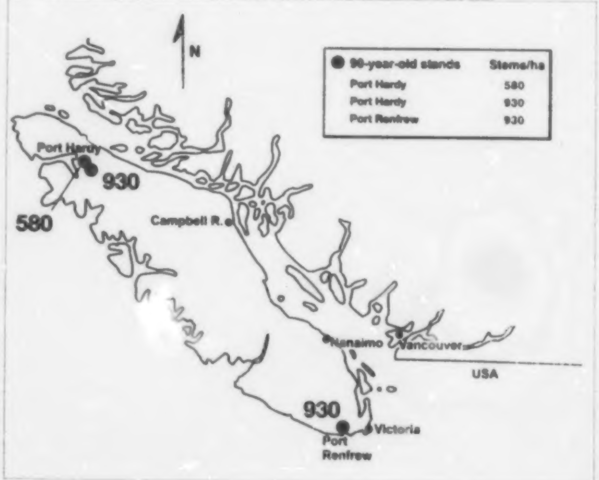
Tree Sample

Three trees representative of small, medium and large diameter class were selected by Forintek Canada Corp. from each of two stands (PH580 and PH930) near Port Hardy and a third stand (PR930) at Port Renfrew on Vancouver Island [14]. The locations are presented in Figure 8-1. An "old-growth" sample was obtained as slabwood from a single, large diameter western hemlock tree, of unknown origin, processed at the Eburne sawmill in Vancouver in 1996.

Fibre Properties

Breast height disks were segregated into seven discrete age classes. Subsamples were air-dried, kraft pulped to a residual lignin content of approximately 5%, [15], then analyzed for fibre length and coarseness by a Kajaani FS200 fibre analyzer.

Figure 8-1
Approximate Locations of Tree Samples



Chip Preparation

The selected log samples were debarked, then segregated by means of a portable sawmill to produce juvenile wood (40 years or less), mature wood (over 40 years) and top wood (40 years or less at the cambium). The 18 wood samples, (6 juvenile, 6 mature and 6 top) were chipped using a 10-knife CM&E disc chipper. For subsequent kraft pulping experiments, well mixed subsamples of the resulting chips were air dried to about 90% solid content and later screened using a Wennberg chip classifier to obtain accept chips in the thickness range of 2 - 6 mm. For the thermomechanical pulping experiments, each of the 18 chip samples were screened on a Burnaby Machinery and Mill Equipment Ltd. two-deck laboratory chip classifier to remove oversize (>31 mm) and the fine (< 8 mm) material. In both cases, the screened chips were well mixed before representative samples were selected for pulping evaluations.

Kraft Pulping

Three 50 gram (oven dried basis) representative samples of the accept chips from each of the 18 samples were cooked in bombs within a B-K micro-digester assembly to produce kraft pulps in the range of 20 to 52 kappa number [15]. The cooking conditions were as follows:

Time to maximum temperature	135 min
Maximum cooking temperature	170°C
Effective alkali, % od weight of wood	17
% Sulphidity	25
Liquor to wood ratio	4.5:1
H factor	1000 - 1800

All the pulps produced were washed, oven dried and weighed to determine pulp yield. Thereafter, the pulps were screened and processed for % rejects and kappa number according to standard procedures. The residual effective alkali of each black liquor sample was determined by barium chloride precipitation and potentiometric titration with hydrochloric acid to pH 8.3.

An estimate of the cooking conditions required to produce kraft pulp at 30 kappa number was completed by fitting a regression line through the kappa/H-factor data obtained for all 18 samples. Pilot scale (30L), kraft pulps were prepared and the resultant pulp properties were determined in accordance with CPPA standard testing methods.

Thermomechanical Pulping (TMP)

First-stage refining was carried out in a 30.5 cm Sunds Defibrator TMP 300 single-disc laboratory refiner. A Bailey Network 90 system was used to control and/or monitor the refining variables. Other pertinent refining conditions for the first-pass refining are shown below.

Plates	rotor, No. 3809 modified stator, No 3804 modified
Preheater pressure	148 kPa
Refiner housing pressure	152 kPa
Refiner housing temperature	135°C
Chip presteaming time	7 min (atmospheric pressure)
Preheater residence time	7 min
Pulp consistency	18 to 20% od pulp (cyclone exit)
Prex compression ratio	3:1

A high freeness pulp sample from each of the primary TMP pulps was given one or two further passes in a 30.5 cm Sprout Waldron open-discharge laboratory refiner equipped with type D2A507 plates at 15-17% refining consistency. Each chip sample was refined at three energy levels to give 54 pulps (6 trees x 3 components x 3 energy levels) in the freeness range from 50 to 160 mL Csf .

Latency was removed from each pulp by the Domtar Method and the resultant pulp was screened on a 6-cut laboratory flat screen. Screen rejects were determined, Bauer-McNett fibre classifications were determined on screened pulps. Fibre lengths of screened pulps were determined on a Kajaani FS-200 instrument. Handsheets were prepared with white water recirculation to minimize the loss of fines and tested for bulk, mechanical, and optical properties using CPPA standard methods.

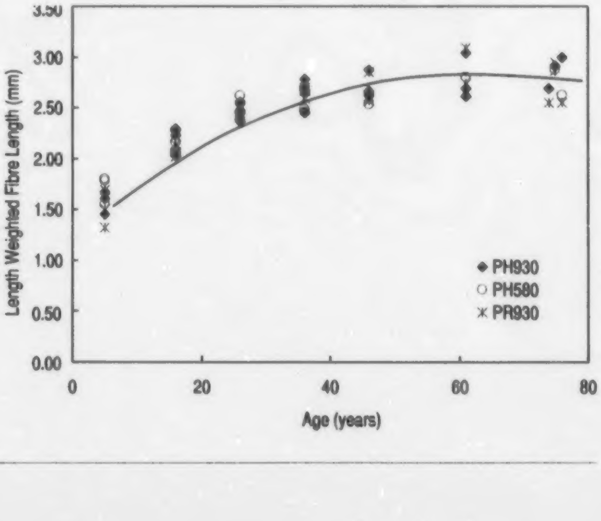
3 Results and Discussion

Fibre Properties

Breast height disk samples were segregated, pulped and the fibre properties determined as described in the experimental section. The results are presented in Figures 8-2 and 8-3, and generalized in Table 8-1.

Given the differences in site quality and geographic location between these samples, there was essentially no difference in both length weighted fibre length (LWFL), and fibre coarseness between the samples as shown, in Figures 8-2

Figure 8-2
Age vs Length Weighted Fibre Length (mm) for Second-growth Western Hemlock



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and 8-3. These data indicate that western hemlock is long and somewhat coarse-fibred and that the juvenile/mature wood transition is approximately 35 years. In Table 8-1, stand level data such as stocking density and site index are included and given these stand level differences one might expect some impact on fibre properties. Closer evaluation of the data in Table 8-1 does indicate that the high site index, low stocking density PH580 stand, which contained much larger trees, and likely a larger live crown, exhibited shorter and less coarse average fibres at age 40-50. This conclusion is tenuous at best given the small sample size and the relatively large standard deviations, shown in parentheses.

For subsequent pilot scale pulping two trees, the extremes for each site in terms of fibre properties and wood density, (not necessarily diameter class) were selected for pilot scale pulping evaluations. This was carried out in order to obtain an indication of the extent of pulping and pulp properties variability for each of the sites. Each stem was segregated into juvenile, mature and topwood at age 40 to ensure the integrity of the mature wood sample – which will likely comprise the bulk of future sawmill residual chip supply.

Kraft Pulping

In Figure 8-4 the kappa/H-factor relationship is presented on the basis of site. An "old-growth" sample, obtained from the slabwood of a large diameter tree, is included in this data for comparison. The variability between PH930 and the PR930 stands, is surprisingly low which is very important in the context of industrial utilization.

However, it is evident that a single tree, the large diameter class sample #74, selected from the PH580 stand was, like the old-growth sample, more difficult to cook (required a greater H-factor), than the other samples, as shown in Table 8-2. However, owing to the very small sample sizes used in this study, the true extent of the pulping variability, may in fact more closely resemble the major data envelope as outlier effects will be diluted within a bulk chip supply.

The individual site data was also analyzed in terms of juvenile, mature and top wood and, as expected from previous studies on second-growth Jack pine and Lodgepole pine [16], no differences in pulping were observed within each tree (Table 8-2). However, this contradicts earlier

Figure 8-3
Age vs Fibre Coarseness (mg/m) for Second-growth Western Hemlock

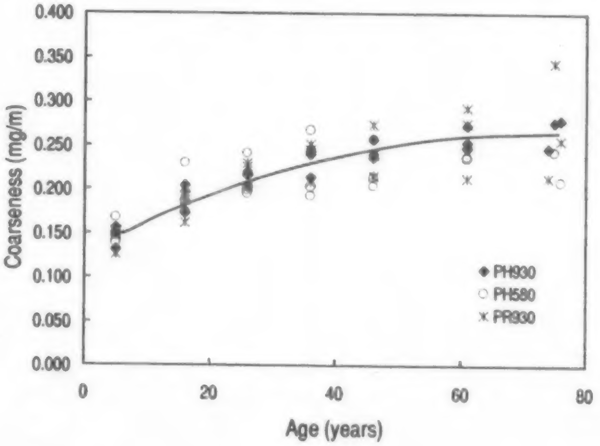

Figure 8-4
H-factor vs Kappa Number for Second-growth Western Hemlock by Site

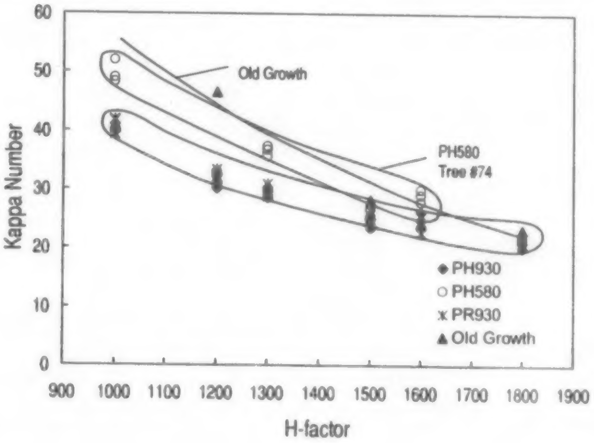

Table 8-1 *Selected Site and Mature Wood Fibre Properties of Second-Growth Western Hemlock*

Stand	Site Index°	Stocking Density (stems/ha)	Average DBH (cm)	LWFL ‡ (mm)*	Coarseness (mg/m)*
PH930	32	930	32.8	2.72 (0.13)	0.245 (0.011)
PH580	39	580	42.7	2.57 (0.06)	0.225 (0.028)
PR930	30	930	32.5	2.68 (0.15)	0.243 (0.030)

‡ LWFL; Length Weighted Average Fibre Length
** for age 40-50 section only (standard deviation).*
NB: the site index, stocking density and DBH data were previously reported above.
(° site index is defined as the height at age 50 and is an indicator of site quality).

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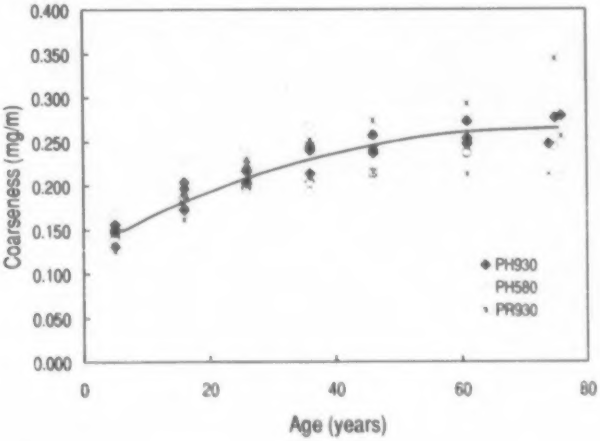
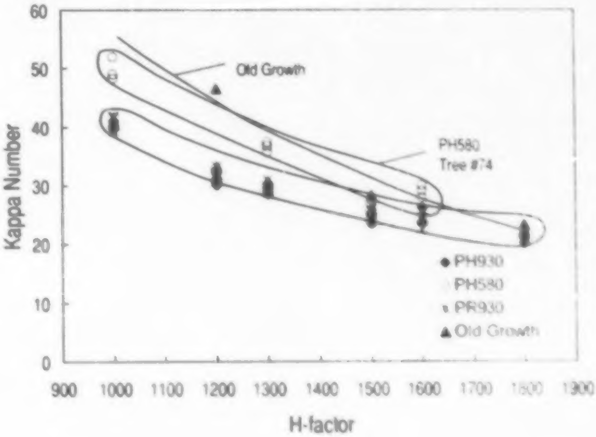


Figure 8-4

H-factor vs Kappa Number for Second-growth Western Hemlock by Site



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Stand	Site Index[a]	Stocking Density (stems/ha)	Average DBH (cm)	LWFL ‡ (mm)*	Coarseness (mg/m)*
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PH580	39	580	42.7	2.57 (0.06)	0.225 (0.028)
PR930	30	930	32.5	2.68 (0.15)	0.243 (0.010)

‡ LWFL: Length Weighted Average Fibre Length

** for age 40-50 section only (standard deviation).*

NB: the site index, stocking density and DBH data were previously reported above.

([a] site index is defined as the height at age 50 and is an indicator of site quality).

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In Figure 8-5 the yield/kappa number relationship is presented on the basis of site and there is very good evidence for a site effect. The PH930 and PR930 stands exhibit similar responses and an average 1-2% superior yield at a given kappa number than the old-growth sample. The PH580 stand generally exhibited a lower pulp yield at a given kappa number and tree #74, which was difficult to cook, also exhibited a much poorer yield.

Table 8-2 *Pulp yield, H-Factor and Effective Alkali Consumed at 30 Kappa Number*

Site	Sample	% Yield Unscreened	H-Factor	% EA Consumed
PH930	71 Juvenile	48.0	1264	10.8
	71 Mature	49.8	1205	10.9
	71 Top	49.3	1228	11.0
	73 Juvenile	48.3	1254	11.1
	73 Mature	49.6	1324	11.2
	73 Top	45.0	1228	11.3
PH580	70 Juvenile	46.1	1319	11.0
	70 Mature	47.3	1275	11.1
	70 Top	47.5	1213	11.2
	74 Juvenile	43.3	1600	11.2
	74 Mature	44.6	1556	11.3
	74 Top	44.9	1507	11.3
PR930	72 Juvenile	47.5	1285	11.0
	72 Mature	49.0	1258	11.1
	72 Top	48.5	1297	10.8
	78 Juvenile	47.6	1233	10.9
	78 Mature	50.2	1253	10.7
	78 Top	47.8	1349	11.4
Old Growth	Mature	47.2	1516	11.3

In Figure 8-6 the yield/kappa data are presented on the basis of juvenile, mature and top wood for all samples. As expected, the juvenile and top wood pulp yield is lower than that of the mature wood by approximately 2% for a given kappa number [16]. This result can be seen more clearly in Table 8-2.

Perhaps the most significant finding is that the pulp yield at kappa 30, approximately 49% for mature wood and 47% for juvenile and top wood, is higher than that previously reported for western hemlock, approximately 44-45% at kappa 28-30 [5,8,9]. The exception was the PH580 fastest grown tree #74, which had a significantly lower yield. The old-growth mature wood sample yield was 47.2%. This result potentially translates into a significant improvement in kraft digester productivity for second-growth western hemlock.

Kraft Pulp Properties

Hatton [16], has reported that due to their shorter finer fibres, juvenile and top wood kraft pulps generally produce a denser, smoother, stronger and more extensible sheet, ideal for low basis weight papers. All test data for these western hemlock samples are included in Appendix I. In Figure 8-7 the tensile index of the PH930 pulps are presented as a function of PFI mill beating. As expected, the finer juvenile and top wood pulps exhibit improved tensile properties over the mature-wood sample. This result was observed for all sites.

In Figure 8-8, the mature wood pulps from all sites are compared with the old-growth sample. Site differences are evident with the PH930 sample exhibiting improved tensile properties at all levels of beating. This result may indicate that these fibres possess thinner cell walls, however this hypothesis requires further analysis by confocal microscopy

Figure 8-5
Kappa Number vs Yield for Second-growth Western Hemlock by Site

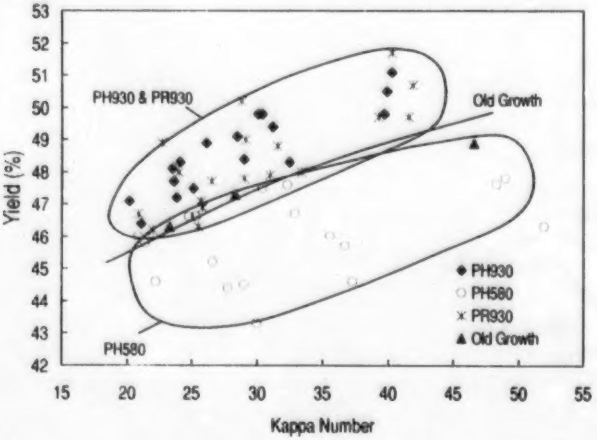


Figure 8-6
Kappa Number vs Yield for Juvenile, Mature and Top Wood Second-growth Western Hemlock

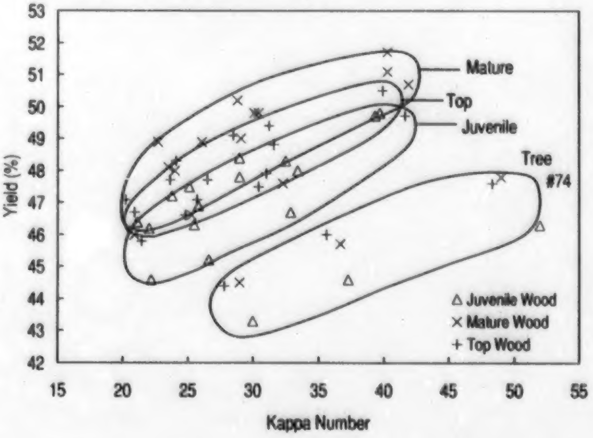


Figure 8-7

PFI Revolutions vs Tensile Index for PH930 Juvenile, Mature and Top Wood Kappa 30 Kraft Pulps

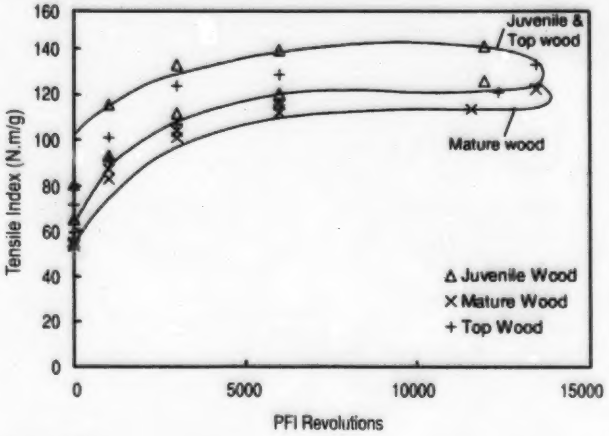


Figure 8-8

PFI Revolutions vs Tensile Index for Kappa 30 Mature Wood Second-growth Western Hemlock Kraft Pulps

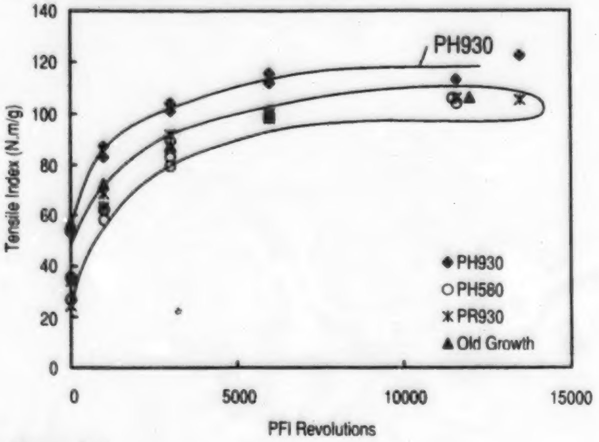


Figure 8-9

Sheet Density vs Tensile Index for Second-growth Western Hemlock

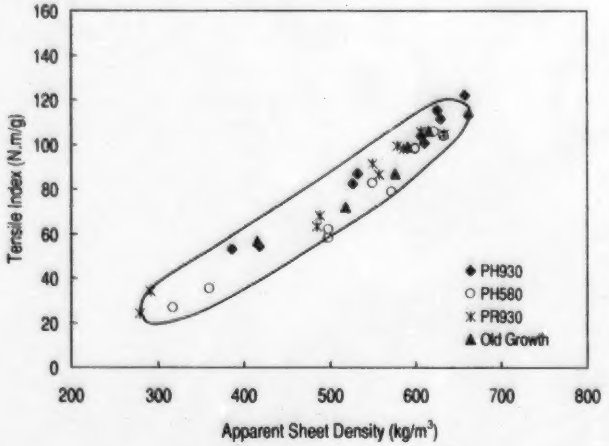
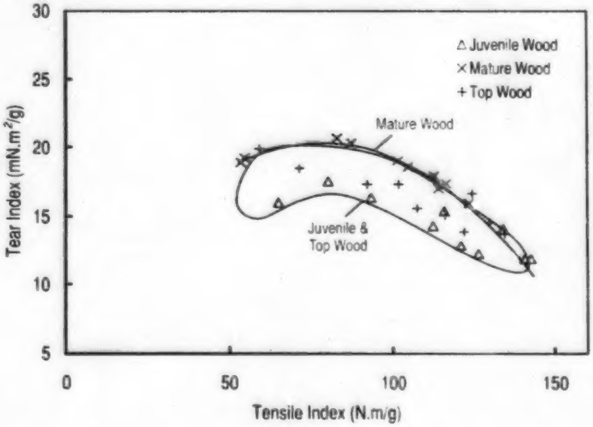


Table 8-3 *Averaged Wood Chip Density and Kraft Pulp Fibre Properties*

	Wood Chip Density (kg/m³)	Length Weighted Fibre Length (mm)	Coarseness (mg/m)
PH930 juvenile	379	2.49	0.216
PH930 top wood	399	2.59	0.229
PH930 mature	443	2.95	0.291
PH580 juvenile	318	2.46	0.214
PH580 top wood	342	2.59	0.225
PH580 mature	368	2.90	0.263
PR930 juvenile	381	2.52	0.224
PR930 top wood	383	2.59	0.230
PR930 mature	443	3.02	0.285
Old growth mature	388	2.86	0.263

Figure 8-10

Tensile Index vs Tear Index for PH930 Juvenile, Mature and Top Wood Second-growth Kappa 30 Western Hemlock Kraft Pulps



as such a conclusion is not evident from the coarseness data in Table 8-3. The old-growth sample exhibits similar tensile properties to the second-growth samples.

In Figure 8-9 the tensile properties of the mature wood pulps are compared as a function of sheet density. In accordance with Figure 8-8, there is no discernible difference between the western hemlock samples, including the old-growth sample, and the overall variability between the sites is very low.

We have also compared the apparent density/tensile index data for juvenile and mature wood samples and found that, unlike other second-growth species studied [16], there was results for coastal Douglas-fir [17] where juvenile wood cooked faster than corresponding mature wood.

In Figure 8-5 the yield/kappa number relationship is presented on the basis of site and there is very good evidence for a site effect. The PH930 and PR930 stands exhibit similar responses and an average 1-2% superior yield at a given kappa number than the old-growth sample. The PH580 stand generally exhibited a lower pulp yield at a given kappa number and tree #74, which was difficult to cook, also exhibited a much poorer yield.

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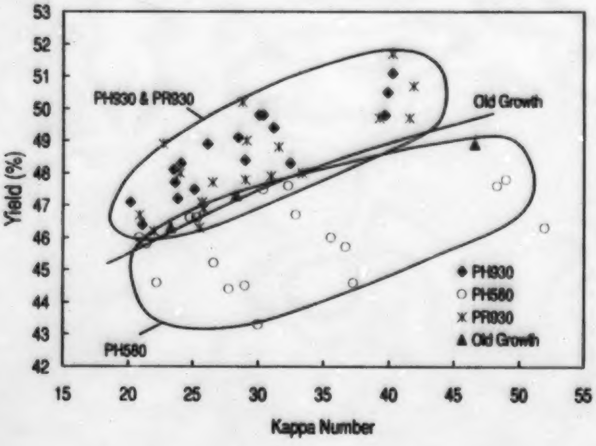


Figure 8-6
Kappa Number vs Yield for Juvenile, Mature and Top Wood Second-growth Western Hemlock

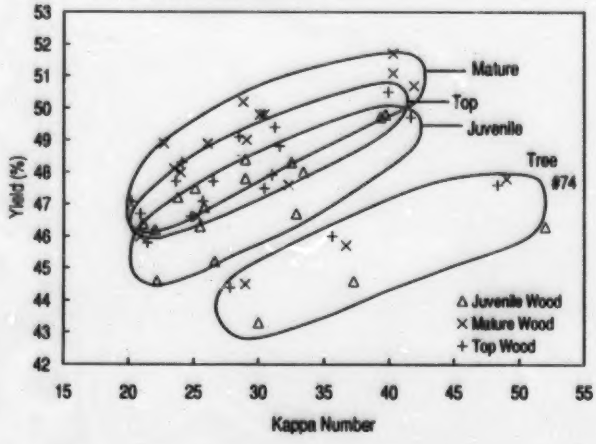


Figure 8-7

PFI Revolutions vs Tensile Index for PH930 Juvenile, Mature and Top Wood Kappa 30 Kraft Pulps

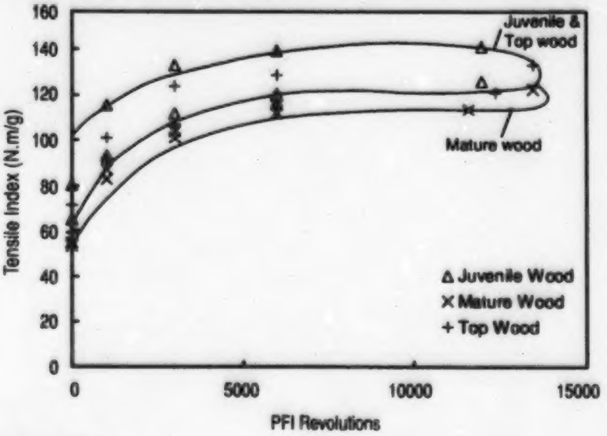


Figure 8-8

PFI Revolutions vs Tensile Index for Kappa 30 Mature Wood Second-growth Western Hemlock Kraft Pulps

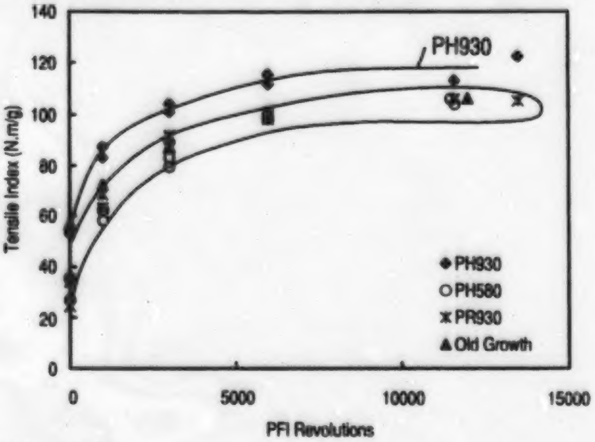


Figure 8-9

Sheet Density vs Tensile Index for Second-growth Western Hemlock

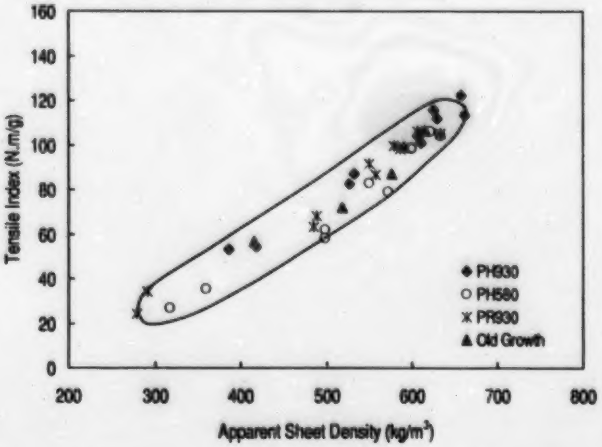
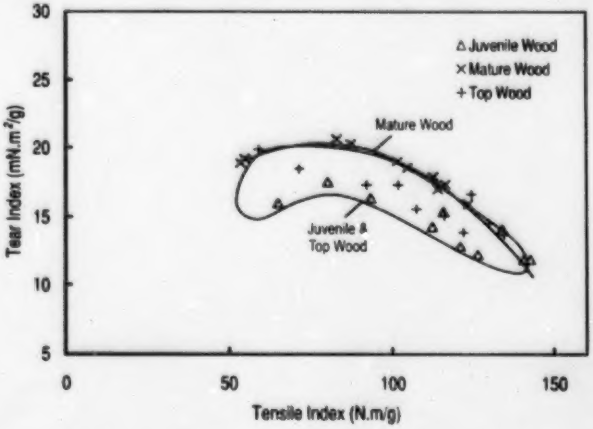


Table 8-3 *Averaged Wood Chip Density and Kraft Pulp Fibre Properties*

	Wood Chip Density (kg/m³)	Length Weighted Fibre Length (mm)	Coarseness (mg/m)
PH930 juvenile	379	2.49	0.216
PH930 top wood	399	2.59	0.229
PH930 mature	443	2.95	0.291
PH580 juvenile	318	2.46	0.214
PH580 top wood	342	2.59	0.225
PH580 mature	368	2.90	0.263
PR930 juvenile	381	2.52	0.224
PR930 top wood	383	2.59	0.230
PR930 mature	443	3.02	0.285
Old growth mature	388	2.86	0.263

Figure 8-10

Tensile Index vs Tear Index for PH930 Juvenile, Mature and Top Wood Second-growth Kappa 30 Western Hemlock Kraft Pulps



as such a conclusion is not evident from the coarseness data in Table 8-3. The old-growth sample exhibits similar tensile properties to the second-growth samples.

In Figure 8-9 the tensile properties of the mature wood pulps are compared as a function of sheet density. In accordance with Figure 8-8, there is no discernible difference between the western hemlock samples, including the old-growth sample, and the overall variability between the sites is very low.

We have also compared the apparent density/tensile index data for juvenile and mature wood samples and found that, unlike other second-growth species studied [16], there was

Figure 8-11
Tensile Index vs Tear Index for Second-growth Kappa 30 Western Hemlock Mature Wood Kraft Pulps

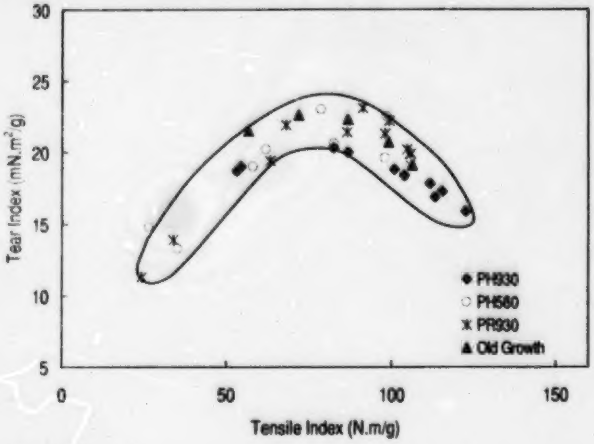
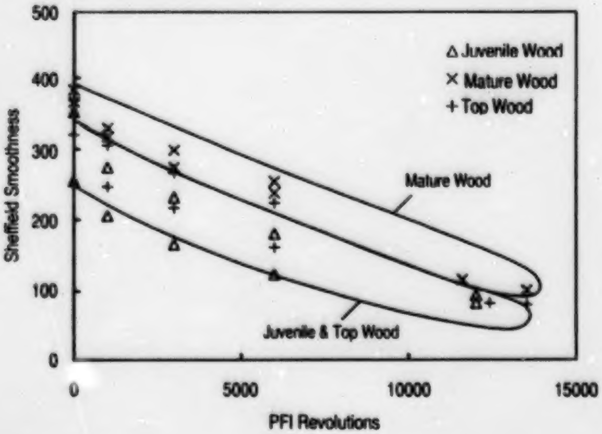


Figure 8-12
PFI Revolutions vs Sheffield Smoothness for PH930 Juvenile, Mature and Top Wood Kappa 30 Second-growth Western Hemlock Kraft Pulps



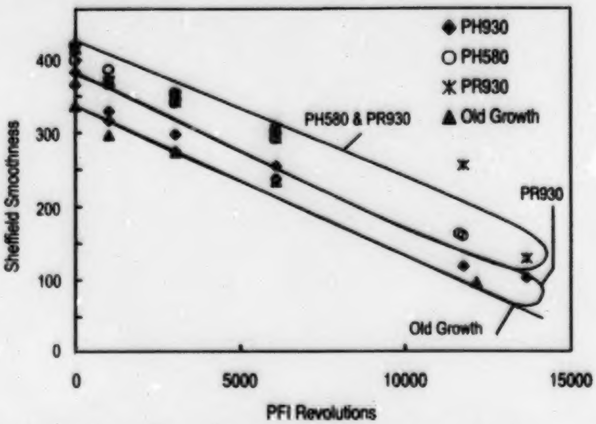
no discernible difference within a given site for western hemlock.

In Figure 8-10, the PH930 juvenile, mature and top wood tear strengths are compared as a function of tensile index. The shorter fibred juvenile and top wood samples are tear deficient as expected [16]. In Figure 8-11, the tensile strengths of the mature wood and old-growth samples are compared as a function of tear index.

The PH930 sample, which we had previously observed as tensile superior in Figure 8-8, is somewhat tear deficient. This is perhaps further evidence that this sample possesses finer "juvenile"-like fibres, by comparison with the other sites.

In Figure 8-12 the Sheffield smoothness of the PH930 juvenile, top and mature wood samples is presented.

Figure 8-13
PFI Revolutions vs Sheffield Smoothness for Kappa 30 Second-growth Western Hemlock Mature Wood Kraft Pulps



Although no difference in sheet density was previously observed, the juvenile and top wood fibres were clearly finer and more collapsible producing a much smoother sheet surface than the mature wood fibres, as expected from [16].

The mature wood samples are compared in Figure 8-13. In accordance with earlier observations the finer fibred PH930, and, surprisingly, the old-growth samples, produced much smoother sheets than the PH580 and PR930 samples.

Comparison with Radiata Pine Kraft Pulp

Coastal western hemlock kraft pulps are, like radiata pine, regarded as true commodity pulps. In order to evaluate similarities and differences we have compared the second-growth western hemlock mature wood kraft pulps with the radiata pine sawmill residual kraft pulps reported by Kibblewhite [18].

In Figure 8-14 tensile index is compared as a function of PFI mill beating. It is very evident that, once pulp strength is fully developed at levels of 6,000 revolutions or greater, coastal western hemlock pulps exhibit a superior tensile strength.

The tensile index is presented as a function of apparent sheet density in Figure 8-15. Clear species differences are apparent, likely due in part to the lower latewood fibre content of coastal western hemlock pulps [19]. Kraft pulp fibres are generally utilized for reinforcement in papersheets with final sheet bulk contributed by hardwood kraft or mechanical pulp fibres.

Tear strength, often used as an indicator of papermaking runnability, is presented as a function of tensile index in Figure 8-16. The importance of maximum fibre strength, the development for western hemlock is evident as at tensile indices greater than 80 N.m/g, the region of maximum fibre development, this species exhibits superior tear strength properties to radiata pine. It is important to note that the western hemlock are single ply tear strengths whereas the

Figure 8-14

PFI Revolutions vs Tensile Index for Western Hemlock Mature Wood and Radiata Pine Sawmill Chip Samples

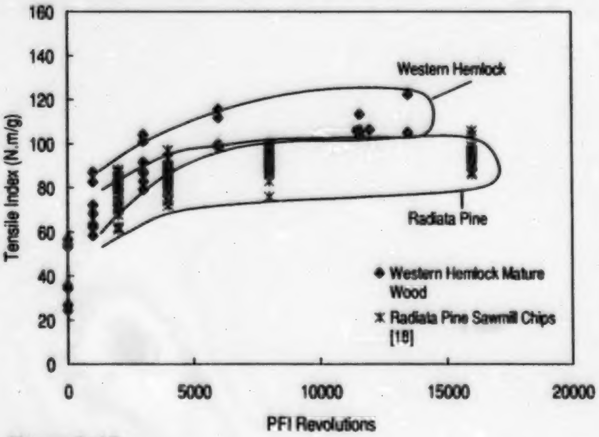


Figure 8-15

Apparent Density vs Tensile Index for Western Hemlock Mature Wood and Radiata Pine Sawmill Chip Samples

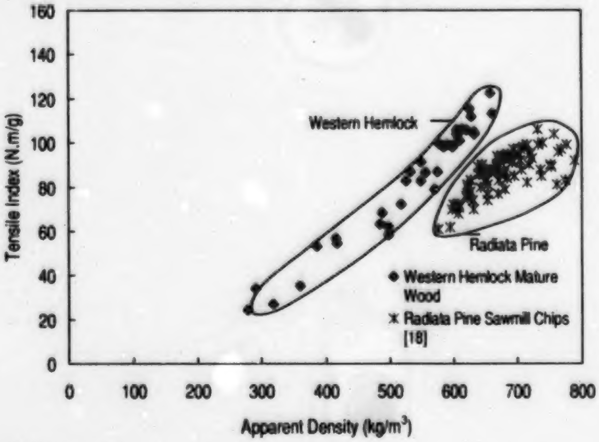
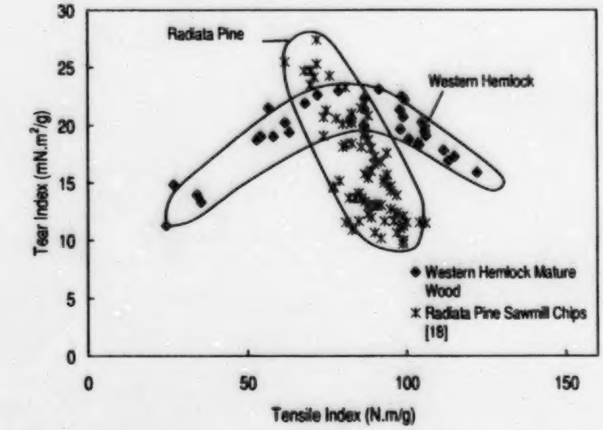


Figure 8-16

Tensile Index vs Tear Index for Western Hemlock Mature Wood and Radiata Pine Sawmill Chip Samples



radiate pine is likely 4-ply which will account for tear differences at lower tensile indices [20].

Thermomechanical Pulping

Raw data for the TMP pulp processing, fibre and handsheet properties are shown in Appendix II and the data have been standardized at 100 mL Canadian standard freeness and 10.0 MJ/kg specific refining energy in Tables 8-4 and 8-5.

Previous studies on second-growth softwood species, [16], indicate that juvenile wood requires more refining energy to achieve a target pulp freeness than mature wood due to the their thin cell walls with higher microfibril angle which absorbs energy. In addition, the mature wood pulps exhibit superior strength properties. The data obtained for second-growth western hemlock exhibit similar trends for refining energy consumption. In Figure 8-17, the PH930 juvenile and top wood exhibit the expected increased refining energy demand over the corresponding mature wood sample. Perhaps the most surprising feature is the low variability observed in these properties.

In Figure 8-18, the mature wood samples from the three sites are compared. Variability is much greater. We had previously observed during the kraft pulping study that the PH930 site exhibited more "juvenile"-like mature wood fibres by comparison with the other sites. This would imply a higher refining energy demand to achieve a target freeness value, which was observed and was surprisingly similar to the PR930 sample. However, from Table 8-3 the PH580 site wood chips exhibit the lowest wood density and from previous work [16] we would expect that lower density wood should be more difficult to refine, in accordance with the juvenile wood results discussed above. However, this was not observed in Figure 8-18 as this sample was in fact easier to refine to a freeness target. The reasons for this observation are not clear.

Figure 8-17

Specific Energy vs Unscreened Freeness for PH930 Second-growth Western Hemlock Juvenile, Mature and Top Wood Thermomechanical Pulps

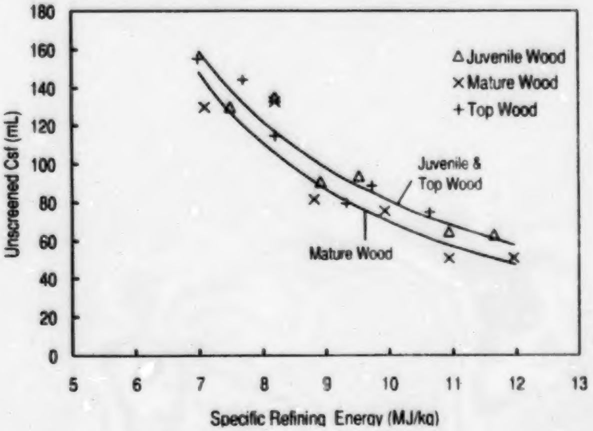


Table 8-4 *Properties of Western Hemlock TMP Pulps at a Freeness of 100 mL Csf*

Site	Tree No.	Wood Sample	Specific Refining Energy (MJ/kg)	Rejects (% od pulp)	Apparent Density (kg/m³)	Burst Index (kPa•m²/g)	Tensile Index (N•m/g)	Tear Index (mN•m²/g)	Brightness (%)	Scattering Coefficient (cm²/g)	R-48 Fraction (%)	Fines (P-200) (%)	Length Weighted Average Fibre Length (mm)
PH930	71	Juvenile	8.5	2.4	365	2.3	44	8.1	52	528	61.0	22.4	1.59
		Mature	8.0	2.0	343	2.2	42	8.6	54	568	61.5	24.5	1.74
		Top	9.2	2.1	367	2.4	44	8.2	52	575	62.8	22.6	1.68
	73	Juvenile	9.3	1.7	353	2.2	43	8.2	53	548	61.0	23.2	1.59
		Mature	9.0	1.6	346	2.2	42	8.7	53	552	61.3	23.1	1.68
		Top	8.7	2.1	358	2.2	43	8.1	51	549	61.0	23.8	1.63
PH580	70	Juvenile	7.7	4.4	369	1.9	38	6.3	52	605	55.5	24.8	1.32
		Mature	7.8	3.1	350	1.8	36	6.9	50	558	58.5	23.8	1.47
		Top	7.6	3.5	362	1.9	39	6.4	50	588	58.0	23.8	1.42
	74	Juvenile	7.9	4.6	330	1.6	34	5.4	51	655	51.5	25.6	1.14
		Mature	8.0	1.0	340	1.8	37	6.9	49	610	56.3	25.4	1.38
		Top	7.7	3.3	335	1.7	36	5.7	51	672	51.9	26.3	1.26
PR930	72	Juvenile	9.7	0.5	360	2.3	45	6.6	53	615	55.1	24.8	1.33
		Mature	9.5	0.9	345	2.1	41	7.9	53	608	56.8	25.6	1.60
		Top	10.8	0.3	378	2.3	44	6.5	51	525	55.9	24.5	1.38
	78	Juvenile	9.7	1.0	371	2.5	46	7.7	52	594	59.8	25.0	1.63
		Mature	9.1	0.5	355	2.4	46	7.8	53	530	60.6	23.5	1.70
		Top	9.7	0.5	368	2.5	47	7.8	51	540	60.9	25.0	1.67
Old Growth			8.8	1.3	298	2.5	44	10.0	50	586	60.7	25.8	1.69

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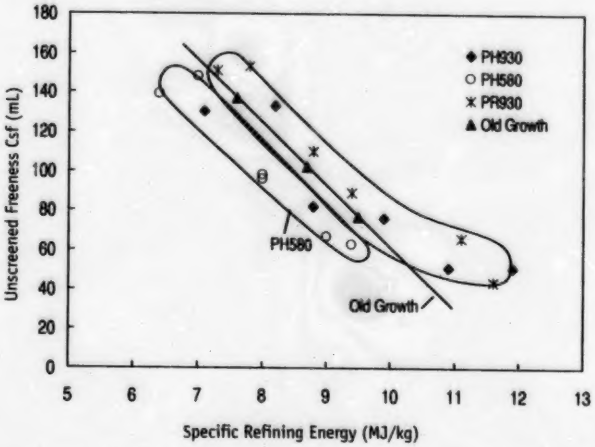
Table 8-5 *Properties of Western Hemlock TMP Pulps at a Specific Energy of 10 MJ/kg*

Site	Tree No.	Wood Sample	Unscreened Csf (mL)	Apparent Density (kg/m³)	Tensile Index (N•m/g)	Tear Index (mN•m²/g)	Scattering Coefficient (cm²/g)	R-48 Fraction (%)	Length Weighted Average Fibre Length (mm)
PH930	71	Juvenile	73	385	47	8.1	540	56.0	1.57
		Mature	60	370	47	8.1	598	57.0	1.63
		Top	83	378	47	8.2	612	61.3	1.67
	73	Juvenile	83	363	45	8.2	558	60.0	1.58
		Mature	76	361	44	8.4	575	58.7	1.57
		Top	63	367	47	7.9	581	56.0	1.47
PH580	70	Juvenile	38	379	45	5.3	635	50.5	1.26
		Mature	55	393	41	6.2	609	52.0	1.29
		Top	62	381	44	6.4	630	55.2	1.40
	74	Juvenile	65	352	39	5.0	692	46.6	1.06
		Mature	56	375	42	5.5	690	49.0	1.20
		Top	59	367	40	5.1	695	47.6	1.14
PR930	72	Juvenile	94	365	45	6.4	630	54.3	1.32
		Mature	88	357	43	7.8	647	54.7	1.60
		Top	128	370	42	6.8	522	58.0	1.40
	78	Juvenile	92	369	48	7.6	600	59.7	1.63
		Mature	75	375	49	8.0	542	58.0	1.58
		Top	87	380	49	7.6	547	58.2	1.61
Old Growth			61	327	50	9.3	690	52.3	1.62

Figure 8-18
Specific Refining Energy vs Unscreened Freeness for Western Hemlock Mature Wood Thermomechanical Pulps



The tensile index is plotted against screened freeness in Figure 8-19 and unlike previous studies on second-growth Douglas-fir, jack pine, and lodgepole pine which indicated that mature wood exhibited improved tensile strength, it is the juvenile and top wood fibres which exhibit superior tensile properties. In Figure 8-20 the PH580 mature wood sample exhibited poorer tensile strength than those from the other sites. This result could imply that the sample responded unfavorably to the refining conditions used in this study and fibre damage occurred which is confirmed in Tables 8-3 and 8-4. This conclusion is also confirmed in Figures 8-21 and 8-22 as the tear strength deficiency observed was due to a much shorter average pulp fibre length. (In Table 8-3 the mature wood kraft pulp fibre lengths were very similar between these mature wood samples).

Another observation was that, under the refining conditions used, the old-growth sample exhibited less fibre cutting, and consequently gave a superior tear strength pulp, than any of the second-growth samples. From these data it is evident

Table 8-5 *Properties of Western Hemlock TMP Pulps at a Specific Energy of 10 MJ/kg*

Site	Tree No.	Wood Sample	Unscreened Csf (mL)	Apparent Density (kg/m²)	Tensile Index (N•m/g)	Tear Index (mN•m²/g)	Scattering Coefficient (cm²/g)	R-48 Fraction (%)	Length Weighted Average Fibre Length (mm)
PH930	71	Juvenile	73	385	47	8.1	540	56.0	1.57
		Mature	60	370	47	8.1	598	57.0	1.63
		Top	83	378	47	8.2	612	61.3	1.67
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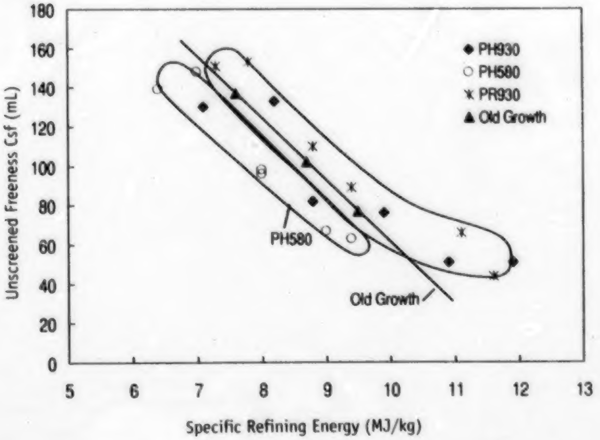
		Mature	55	393	41	6.2	609	52.0	1.29
		Top	62	381	44	6.4	630	55.2	1.40
	74	Juvenile	65	352	39	5.0	692	46.6	1.06
		Mature	56	375	42	5.5	690	49.0	1.20
		Top	59	367	40	5.1	695	47.6	1.14
PR930	72	Juvenile	94	365	45	6.4	630	54.3	1.32
		Mature	88	357	43	7.8	647	54.7	1.60
		Top	128	370	42	6.8	522	58.0	1.40
	78	Juvenile	92	369	48	7.6	600	59.7	1.63
		Mature	75	375	49	8.0	542	58.0	1.58
		Top	87	380	49	7.6	547	58.2	1.61
Old Growth			61	327	50	9.3	690	52.3	1.62

Figure 8-18
Specific Refining Energy vs Unscreened Freeness for Western Hemlock Mature Wood Thermomechanical Pulps



The tensile index is plotted against screened freeness in Figure 8-19 and unlike previous studies on second-growth Douglas-fir, jack pine, and lodgepole pine which indicated that mature wood exhibited improved tensile strength, it is the juvenile and top wood fibres which exhibit superior tensile properties. In Figure 8-20 the PH580 mature wood sample exhibited poorer tensile strength than those from the other sites. This result could imply that the sample responded unfavorably to the refining conditions used in this study and fibre damage occurred which is confirmed in Tables 8-3 and 8-4. This conclusion is also confirmed in Figures 8-21 and 8-22 as the tear strength deficiency observed was due to a much shorter average pulp fibre length. (In Table 8-3 the mature wood kraft pulp fibre lengths were very similar between these mature wood samples).

Another observation was that, under the refining conditions used, the old-growth sample exhibited less fibre cutting, and consequently gave a superior tear strength pulp, than any of the second-growth samples. From these data it is evident

Figure 8-19

Screened Freeness vs Tensile Index for PH930 Second-growth Western Hemlock Juvenile Mature and Top Wood Thermomechanical Pulps

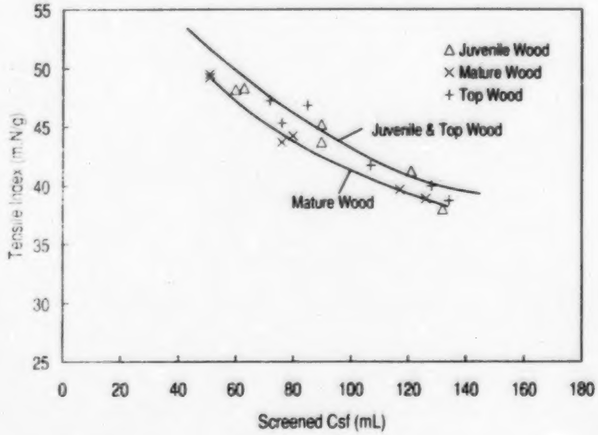


Figure 8-20

Screened Freeness vs Tensile Index for Western Hemlock Mature Wood Thermomechanical Pulps

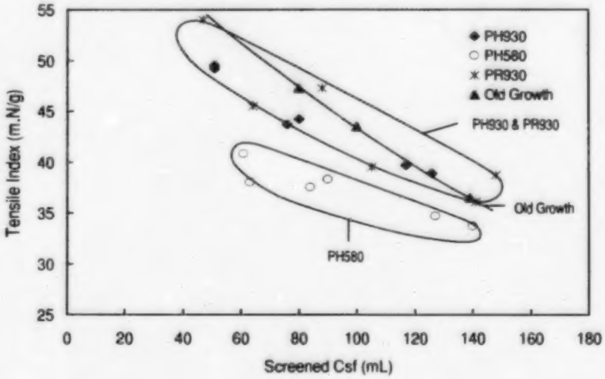


Figure 8-21

Screened Freeness vs Tear Index for Western Hemlock Mature Wood Thermomechanical Pulps

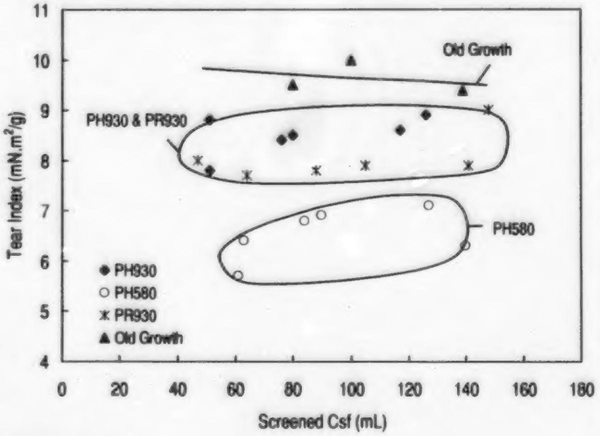
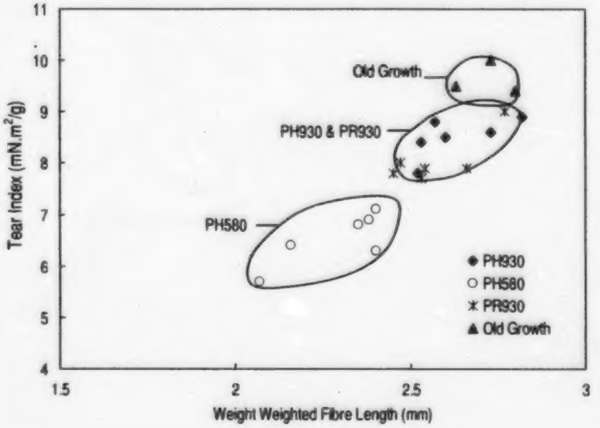


Figure 8-22

Weight Weighted Average Fibre Length vs Tear Index for Western Hemlock Mature Wood Thermomechanical Pulps



that in order to retain fibre length in second-growth wood, the refining conditions must be modified to match the quality of the incoming wood sample as has recently been reported for Jack pine [21] and radiata pine [22].

Due to substantial differences in refining capability between Paprican and radiata pine researchers, it is not valid to undertake direct comparisons of mechanical pulp properties.

4 Conclusions

The most significant findings of this project were as follows. Fibre properties were uniform between the three sites. In addition, the pulping and pulp properties were also generally uniform. The kraft pulp yield of second-growth western hemlock was 1-2% higher at kappa 30 than reported literature values and this could mean a significant improvement in digester productivity. The properties of second-growth western hemlock are very similar to those of old growth. It was also evident that, in order to take advantage of differences in pulp properties, juvenile and mature wood should be segregated, i.e. thinnings will offer an additional product opportunity. Well beaten kraft pulps from western hemlock offer reduced bulk and improved tear and tensile strengths over radiata pine. In addition, second-growth western hemlock kraft pulps exhibit excellent extensibility and could perhaps be considered for alternative products. TMP refining conditions must be modified to fit the incoming raw material in order to deliver maximum pulp properties from second-growth western hemlock.

The site influence on pulping and pulp properties observed were not quantifiable on the basis of the gross wood and fibre properties recorded in this study. They are likely due to genetic differences. The PR930 stems were consistent throughout. The PH930 stems likely produced finer fibred "juvenile"-like kraft pulps with improved tensile but poorer tear strength properties. The PH580 stems were more difficult to kraft pulp, but this did not affect kraft pulp properties, with the exception of stretch. These PH580 stems were easier to thermomechanically pulp however this resulted in a reduction in fibre length which detrimentally affected TMP pulp strength.

Finally, the very low level of variation observed in the pulping and pulp properties of second-growth western hemlock may be attributed in part to the very small sample size used in this study. More variable samples, such as PH580 tree #74, would likely be less observable in bulk chip samples.

5 Acknowledgements

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Appendix I

Properties of Kraft Pulps from Western Hemlock Juvenile Wood, Mature Wood and Top Wood

Table [illegible] PH580

Sample	70 Juvenile					70 Mature					70 Top				
PFI Rev.	0	1000	3000	6000	12000	0	1000	3000	6000	11600	0	1000	3000	6000	12400
Screened Csf (mL)	738	730	680	570	303	761	744	718	578	262	743	732	682	564	260
Apparent Density (kg/m³) (1 Sheet)	452	585	645	680	719	386	532	610	629	662	412	543	617	654	685
Burst Index (kPa•m²/g)	4.0	6.5	8.5	9.5	10.6	2.8	5.0	7.2	8.3	8.8	3.6	5.7	7.7	8.9	9.4
Breaking length (km)	6.6	9.5	11.4	12.2	12.8	5.4	8.9	10.3	11.4	11.6	6.0	9.3	10.9	11.7	12.3
Tensile Index (N•m/g)	64.8	92.9	111.5	120.1	125.6	53.2	86.9	100.9	111.8	113.3	58.9	91.5	106.8	115.2	120.9
Tensile Energy Absorbtion (T.E.A) Index (mJ/g)	616	1492	2144	2438	2629	416	1240	1776	2092	2246	573	1337	1854	2165	2484
Stretch (%)	1.48	2.48	2.99	3.17	3.30	1.23	2.14	2.75	2.92	3.12	1.51	2.25	2.76	2.99	3.25
Tear Index (mN•m²/g) (1 Ply)	16.0	16.3	14.4	13.1	12.5	18.7	20.0	18.8	17.8	16.9	19.6	17.2	15.6	15.1	14.0
Tear Index (mN•m²/g) (4 Ply)	22.8	17.8	13.4	12.4	11.7	25.0	27.0	19.1	16.6	15.9	26.1	19.5	15.4	13.0	12.6
Zero Span Breaking Length (km)	21.1	20.7	20.6	21.3	20.3	21.3	20.4	21.2	20.5	21.1	22.5	21.1	20.9	20.9	20.7
Air Resistance (Gurley) (sec/100 mL)	0.9	3.0	5.0	14.0	142.0	0.3	0.7	2.0	5.0	88.0	0.5	1.0	3.0	8.0	200.0
Sheffield Smoothness	352	274	231	180	94	383	329	298	254	116	368	305	266	223	82
Opacity (%)	96.6	94.8	93.6	91.9	90.1	96.2	95.8	90.2	92.3	91.3	96.3	94.7	93.2	91.4	90.7
Sample	**74 Juvenile**					**74 Mature**					**74 Top**				
PFI Rev.	0	1000	3000	6000	12000	0	1000	3000	6000	13500	0	1000	3000	6000	13500
Screened Csf (mL)	715	699	647	539	317	751	736	696	578	219	739	716	662	556	250
Apparent Density (kg/m³) (1 Sheet)	549	633	685	719	746	418	526	606	625	658	463	588	654	685	709
Burst Index (kPa•m²/g)	5.2	8.2	9.8	10.7	11.2	3.1	5.9	8.0	9.2	10.0	4.4	7.4	9.2	10.1	10.5
Breaking length (km)	8.1	11.7	13.5	14.2	14.4	5.6	8.4	10.6	11.8	12.5	7.2	10.3	12.6	13.1	13.6
Tensile Index (N•m/g)	79.9	115.0	132.7	139.2	141.4	54.5	82.6	103.9	115.4	122.4	71.1	101.0	123.4	128.8	133.3
Tensile Energy Absorbtion (T.E.A) Index (mJ/g)	889	1870	2542	2873	2994	462	1146	1863	2284	2506	601	1548	2339	2632	2885
Stretch (%)	1.69	2.51	2.99	3.23	3.31	1.30	2.12	2.79	3.08	3.19	1.33	2.37	2.97	3.21	3.47
Tear Index (mN•m²/g) (1 Ply)	17.4	15.4	14.2	12.2	12.2	19.0	20.3	18.4	17.3	15.9	18.3	17.2	16.6	14.6	13.9
Tear Index (mN•m²/g) (4 Ply)	19.0	14.2	11.5	10.4	9.8	27.2	25.7	19.9	15.9	14.5	24.9	18.4	14.4	12.8	11.9
Zero Span Breaking Length (km)	22.2	21.8	21.4	21.6	21.2	21.3	21.5	21.7	21.8	21.9	22.4	22.3	22.2	21.6	20.5
Air Resistance (Gurley) (sec/100 mL)	2.0	6.0	11.0	36.0	156.0	0.3	0.8	2.0	6.0	90.0	1.0	2.0	4.0	14.0	118.0
Sheffield Smoothness	255	205	165	123	82	366	317	274	237	101	320	246	216	161	80
Opacity (%)	97.2	96.0	92.9	92.3	91.0	96.4	93.7	93.4	91.1	91.2	96.9	97.6	92.8	92.7	92.3

Table B-2 **PH930**

Sample	71 Juvenile					71 Mature					71 Top				
PFI Rev.	0	1000	3000	6000	12000	0	1000	3000	6000	11600	0	1000	3000	6000	13000
Screened Csf (mL)	747	725	695	594	320	771	761	720	572	272	758	744	714	596	316
Apparent Density (kg/m³) (1 Sheet)	413	637	645	654	667	318	498	549	599	633	382	513	565	629	662
Burst Index (kPa•m²/g)	3.1	5.6	7.3	9.0	10.2	1.8	3.6	5.6	7.3	7.9	3.1	5.3	7.2	9.0	9.9
Breaking length (km)	5.1	7.9	10.3	11.7	12.6	2.7	5.9	8.4	10.0	10.6	5.1	8.0	10.3	11.4	12.2
Tensile Index (N•m/g)	50.1	77.6	101.1	114.3	123.9	26.8	58.2	82.8	98.2	104.0	49.6	78.6	100.6	111.6	119.2
Tensile Energy Absorbtion (T.E.A) Index (mJ/g)	388	1032	1745	2309	2753	137	652	1291	1919	2218	411	1103	1813	2130	2518
Stretch (%)	1.24	2.08	2.73	3.21	3.56	0.81	1.69	2.36	3.02	3.29	1.29	2.17	2.80	3.01	3.35
Tear Index (mN•m²/g) (1 Ply)	16.4	17.9	18.3	17.2	17.1	14.8	19.0	20.6	19.6	18.3	18.3	18.3	17.9	17.8	16.6
Tear Index (mN•m²/g) (4 Ply)	23.6	28.8	21.0	17.8	15.8	13.9	30.9	28.6	22.0	19.9	25.6	27.3	20.5	17.1	15.9
Zero Span Breaking Length (km)	21.3	21.1	20.9	21.1	20.8	21.7	21.5	21.5	20.7	20.4	22.1	22.5	22.1	21.8	21.4
Air Resistance (Gurley) (sec/100 mL)	0.4	0.8	2.0	5.0	56.0	0.1	0.2	0.4	2.0	47.0	0.4	0.8	1.0	5.0	51.0
Sheffield Smoothness	372	320	289	243	135	418	386	353	301	157	379	328	293	246	138
Opacity (%)	97.0	94.0	93.0	93.0	92.0	97.0	93.0	92.0	92.0	92.0	97.0	93.0	92.0	92.0	92.0

Sample	73 Juvenile					73 Mature					73 Top				
PFI Rev.	0	1000	3000	6000	14600	0	1000	3000	6000	11500	0	1000	3000	6000	12000
Screened Csf (mL)	748	739	698	592	270	764	758	714	570	254	754	747	717	606	312
Apparent Density (kg/m³) (1 Sheet)	441	562	621	645	680	360	498	571	599	621	435	541	592	621	645
Burst Index (kPa•m²/g)	2.9	5.1	7.0	8.4	9.2	1.7	3.6	5.5	7.0	8.5	2.4	4.2	6.1	7.5	8.7
Breaking length (km)	5.6	8.1	10.2	11.0	11.5	3.6	6.3	8.0	10.1	10.8	5.1	7.1	8.7	10.3	10.7
Tensile Index (N•m/g)	55.0	79.8	100.5	108.3	113.2	35.4	62.0	78.9	98.7	105.8	49.7	69.6	84.9	101.4	104.9
Tensile Energy Absorbtion (T.E.A) Index (mJ/g)	439	1053	1776	2135	2369	188	657	1179	1794	2113	354	826	354	1781	2070
Stretch (%)	1.23	2.00	2.70	3.05	3.24	0.90	1.59	2.24	2.78	3.08	1.11	1.79	2.43	2.72	3.06
Tear Index (mN•m²/g) (1 Ply)	17.6	17.5	18.0	17.3	17.2	13.3	20.2	23.0	22.5	19.5	16.1	18.6	19.7	18.7	16.9
Tear Index (mN•m²/g) (4 Ply)	24.6	26.6	20.0	17.3	16.5	18.2	34.2	30.2	22.9	21.3	26.0	27.7	23.2	19.2	17.4
Zero Span Breaking Length (km)	22.1	22.9	21.9	21.8	21.8	22.7	22.6	21.2	21.3	20.8	21.7	22.7	22.4	22.5	21.5
Air Resistance (Gurley) (sec/100 mL)	0.4	1.0	2.0	4.0	11.0	0.1	0.2	0.6	3.0	28.0	0.3	0.5	0.9	4.0	32.0
Sheffield Smoothness	355	305	286	250	110	398	366	340	290	160	365	331	303	273	160
Opacity (%)	96.3	95.4	93.7	93.4	92.3	94.2	92.1	91.8	90.2	90.5	94.7	93.9	92.4	89.4	90.8

Table I — 3 *PR930*

Sample	72 Juvenile					72 Mature					72 Top				
PFI Rev.	0	1000	3000	6000	11600	0	1000	3000	6000	11600	0	1000	3000	6000	11600
Screened Csf (mL)	751	731	695	588	318	771	758	708	562	246	751	741	698	578	300
Apparent Density (kg/m³) (1 Sheet)	362	556	617	641	662	291	488	549	578	606	315	535	595	629	658
Burst Index (kPa•m²/g)	2.8	5.2	7.7	9.2	9.9	1.5	3.7	5.9	7.3	8.3	2.2	5.1	7.2	8.6	9.6
Breaking length (km)	5.0	8.1	10.7	11.7	12.0	3.5	7.0	9.3	10.1	10.8	3.8	7.6	10.0	11.5	12.6
Tensile Index (N•m/g)	49.4	79.7	104.6	115.1	117.9	34.1	68.2	91.5	99.5	105.9	37.7	75.0	98.2	112.7	123.2
Tensile Energy Absorbtion (T.E.A) Index (mJ/g)	416	1169	1905	2384	2532	213	889	1628	1910	2416	256	1037	1752	2245	2578
Stretch (%)	1.32	2.23	2.85	3.26	3.39	1.02	1.96	2.72	2.96	3.54	1.09	2.11	2.78	3.14	3.30
Tear Index (mN•m²/g) (1 Ply)	16.3	18.5	18.0	16.3	15.9	13.9	21.9	23.1	22.2	19.9	14.2	19.1	19.9	17.5	16.7
Tear Index (mN•m²/g) (4 Ply)	24.8	27.2	18.7	17.3	15.4	18.3	35.9	32.6	24.7	20.9	21.5	25.8	22.3	17.5	15.7
Zero Span Breaking Length (km)	20.0	20.0	20.6	20.8	20.9	22.6	22.2	21.9	21.4	21.2	21.3	22.4	21.6	21.5	21.0
Air Resistance (Gurley) (sec/100 mL)	0.3	0.8	2.0	3.0	65.0	0.1	0.3	0.6	2.0	39.0	0.2	0.5	1.0	5.0	65.0
Sheffield Smoothness	400	327	287	242	117	414	369	342	292	154	410	338	302	254	122
Opacity (%)	96.9	95.3	95.0	93.7	92.8	95.3	92.5	92.2	92.1	90.8	97.9	95.3	93.3	93.0	92.1

Sample	78 Juvenile					78 Mature					78 Top				
PFI Rev.	0	1000	3000	6000	15000	0	1000	3000	6000	13500	0	1000	3000	6000	12000
Screened Csf (mL)	761	747	722	632	274	769	764	730	602	213	757	743	696	574	301
Apparent Density (kg/m³) (1 Sheet)	478	595	645	667	694	279	485	556	585	633	347	559	633	667	699
Burst Index (kPa•m²/g)	3.1	5.5	7.2	8.3	8.8	0.9	3.3	5.4	7.0	8.8	2.2	5.4	7.8	9.0	10.0
Breaking length (km)	6.4	8.8	10.8	11.4	12.1	2.5	6.5	8.8	10.0	10.7	4.5	8.1	10.7	12.0	12.3
Tensile Index (N•m/g)	62.3	85.9	105.5	112.1	119.1	24.4	63.3	86.7	98.1	104.9	43.7	79.6	105.1	118.1	121.1
Tensile Energy Absorbtion (T.E.A) Index (mJ/g)	564	1309	2024	2370	2589	94	667	1340	1657	2206	298	1171	2041	2515	2639
Stretch (%)	1.40	2.33	2.98	3.29	3.38	0.62	1.62	2.37	2.59	3.24	1.09	2.23	3.00	3.33	3.44
Tear Index (mN•m²/g) (1 Ply)	18.3	17.9	17.9	16.5	16.6	11.3	19.4	21.4	21.3	20.2	15.4	19.5	17.6	15.7	15.3
Tear Index (mN•m²/g) (4 Ply)	27.9	20.9	17.2	15.4	14.8	14.8	28.9	30.5	24.5	19.3	20.9	25.9	18.4	15.8	14.5
Zero Span Breaking Length (km)	23.9	22.6	21.8	21.3	21.2	22.8	22.9	21.7	21.9	21.3	21.3	22.9	21.5	20.7	20.4
Air Resistance (Gurley) (sec/100 mL)	0.7	2.0	3.0	6.0	102.0	0.1	0.2	0.4	2.0	75.0	0.2	0.8	2.0	7.0	60.0
Sheffield Smoothness	323	278	267	239	103	416	372	351	305	127	379	308	272	232	125
Opacity (%)	95.7	95.4	94.3	90.6	90.6	97.0	93.5	91.6	90.8	90.3	97.9	95.2	93.2	91.1	90.6

Table [illegible] Old Growth

Sample	Western Hemlock				
PFI Rev.	0	100	3000	6000	12000
Screened Csf (mL)	719	716	669	556	252
Apparent Density (kg/m^3) (1 Sheet	416	518	575	590	615
Burst Index (kPa•m^2/g)	4.3	5.6	7.5	8.1	8.7
Breaking length (km)	5.8	7.4	8.9	10.1	10.8
Tensile Index (N•m/g)	56.8	72.1	87.0	99.1	106.2
Zero Span Breaking Length (km)	19.7	18.1	17.6	18.5	19.9
TEA Index (mJ/g)	544.8	1008	1445	1951	2125
Stretch (%)	1.52	2.17	2.61	3.05	3.12
Tear Index (mN•m^2/g) (1 Ply)	34.8	30.7	22.6	20.0	17.9
Tear Index (mN•m^2/g) (4 Ply)	21.5	22.6	22.3	20.7	19.1
Air Resistance (Gurley) (sec/100 mL)	0.6	0.9	1.9	5.0	107.0
Sheffield Smoothness	337	297	273	233	94
Opacity (%)	97.4				

Appendix II

Properties of TMP Pulps from Western Hemlock Juvenile Wood, Mature Wood and Top Wood

Table 11 – 1 **PH580**

Sample	**70 Juvenile**			**70 Mature**			**70 Top**		
Unscreened Csf (mL)	58	79	117	67	98	139	75	98	150
Specific Energy (MJ/kg)	9.1	8.4	7.1	9.0	8.0	6.4	9.4	7.6	6.2
Screened Csf (mL)	51	72	107	63	84	127	70	94	128
Reject (% od pulp)	2.6	3.7	5.1	1.5	3.0	5.6	2.2	3.5	5.7
Apparent Density (kg/m^3) (1 Sheet)	376	372	368	383	365	326	379	367	340
Burst Index (kPa•m^2/g)	2.2	2.0	1.9	2.0	1.9	1.6	2.2	2.0	1.7
Tensile Index (N•m/g)	43.0	39.8	37.3	38.0	37.5	34.7	41.9	39.7	34.6
Stretch (%)	1.99	1.92	1.77	1.63	1.90	1.79	1.95	1.82	1.79
Tear Index (mN•m^2/g) (4 Ply)	5.4	6.2	6.3	6.4	6.8	7.1	6.4	6.4	6.5
Brightness (%)	52	52	51	50	50	49	50	50	50
Opacity (%)	97.9	97.9	97.8	98.0	97.8	97.5	98.2	98.4	97.6
Scat. Coefficient (cm^2/g)	629	622	602	590	569	539	612	595	542
R-48 fraction (%)	51.1	54.1	55.8	53.7	57.3	59.4	56.0	57.6	59.9
Fines (P-200) (%)	28.2	25.3	24.8	25.2	23.6	23.9	24.3	24.4	23.0
W. Weighted Average Fibre Length (mm)	2.02	2.06	2.09	2.16	2.35	2.40	2.17	2.15	2.30
L. Weighted Average Fibre Length (mm)	1.28	1.30	1.33	1.33	1.44	1.49	1.41	1.37	1.48
Arithmetic Average Fibre Length (mm)	0.47	0.46	0.48	0.46	0.48	0.49	0.51	0.50	0.53
Sample	**74 Juvenile**			**74 Mature**			**74 Top**		
Unscreened Csf (mL)	65	80	127	63	96	148	59	81	131
Specific Energy (MJ/kg)	10.0	8.5	7.1	9.4	8.0	7.0	10.0	8.4	6.6
Screened Csf (mL)	63	78	107	61	90	140	58	77	110
Reject (% od pulp)	2.0	2.2	7.2	0.2	1.0	1.5	1.4	1.8	5.3
Apparent Density (kg/m^3) (1 Sheet)	352	335	327	360	366	315	367	354	327
Burst Index (kPa•m^2/g)	1.9	1.7	1.5	2.0	1.9	1.6	2.1	1.8	1.6
Tensile Index (N•m/g)	39.4	35.9	32.8	40.8	38.3	33.7	40.4	39.4	34.9
Stretch (%)	2.11	1.72	1.86	1.89	1.87	1.79	1.88	1.89	1.83
Tear Index (mN•m^2/g) (4 Ply)	5.0	5.4	5.4	5.7	6.9	6.3	5.1	5.6	6.0
Brightness (%)	51	51	50	49	49	48	51	51	50
Opacity (%)	98.9	98.8	98.4	98.9	98.7	98.2	98.8	98.9	98.8
Scat. Coefficient (cm^2/g)	692	693	647	671	615	585	695	687	666
R-48 fraction (%)	46.6	46.6	52.3	50.0	56.3	56.7	47.6	48.2	53.4
Fines (P-200) (%)	28.6	27.2	25.1	26.3	25.4	24.5	31.3	27.1	26.5
W. Weighted Average Fibre Length (mm)	1.75	1.81	1.90	2.07	2.38	2.40	1.87	1.93	2.10
L. Weighted Average Fibre Length (mm)	1.06	1.11	1.15	1.23	1.43	1.41	1.14	1.18	1.29
Arithmetic Average Fibre Length (mm)	0.42	0.42	0.43	0.44	0.48	0.47	0.44	0.44	0.47

Table II – 2 ***PH930***

Sample	71 Juvenile			71 Mature			71 Top		
Unscreened Csf (mL)	65	91	130	51	82	130	75	89	144
Specific Energy (MJ/kg)	10.9	8.9	7.5	10.9	8.8	7.1	10.6	9.7	7.7
Screened Csf (mL)	60	90	121	51	80	117	72	85	128
Reject (% od pulp)	1.1	2.1	4.0	0.5	1.4	3.1	1.3	1.5	4.3
Apparent Density (kg/m^3) (1 Sheet)	393	381	339	381	357	330	389	372	355
Burst Index (kPa•m^2/g)	2.5	2.4	2.1	2.6	2.4	2.1	2.7	2.5	2.4
Tensile Index (N•m/g)	48.2	45.2	41.2	49.2	44.2	39.7	47.2	46.8	40.0
Stretch (%)	2.06	1.94	1.88	1.99	2.05	1.95	2.01	2.14	1.86
Tear Index (mN•m^2/g) (4 Ply)	8.1	8.1	8.0	7.8	8.5	8.6	8.3	8.2	8.1
Brightness (%)	51	52	51	54	54	53	51	52	51
Opacity (%)	97.3	96.9	96.9	97.5	97.4	96.8	98.7	97.8	96.4
Scat. Coefficient (cm^2/g)	552	528	526	604	596	549	651	595	508
R-48 fraction (%)	51.4	61.0	64.2	54.6	59.8	62.6	60.3	61.7	65.2
Fines (P-200) (%)	24.7	23.0	21.1	27.9	25.2	24.1	24.1	23.1	21.4
W. Weighted Average Fibre Length (mm)	2.35	2.37	2.40	2.52	2.60	2.73	2.43	2.47	2.50
L. Weighted Average Fibre Length (mm)	1.56	1.59	1.61	1.58	1.69	1.79	1.66	1.67	1.73
Arithmetic Average Fibre Length (mm)	0.57	0.58	0.58	0.51	0.53	0.56	0.60	0.60	0.63

Sample	73 Juvenile			73 Mature			73 Top		
Unscreened Csf (mL)	63	94	135	51	76	133	80	115	155
Specific Energy (MJ/kg)	11.6	9.5	8.2	11.9	9.9	8.2	9.3	8.2	7.0
Screened Csf (mL)	63	90	132	51	76	126	76	107	134
Reject (% od pulp)	1.2	1.5	2.8	0.6	1.0	2.7	1.3	2.7	4.7
Apparent Density (kg/m^3) (1 Sheet)	374	362	319	379	361	329	362	359	338
Burst Index (kPa•m^2/g)	2.7	2.3	2.0	2.7	2.3	2.1	2.4	2.2	2.1
Tensile Index (N•m/g)	48.3	43.7	38.0	49.5	43.7	38.9	45.3	41.7	38.7
Stretch (%)	2.18	2.03	1.78	2.13	2.01	1.98	2.04	1.93	1.86
Tear Index (mN•m^2/g) (4 Ply)	7.6	8.2	8.0	8.8	8.4	8.9	7.9	8.1	8.1
Brightness (%)	52	53	53	53	53	53	52	51	50
Opacity (%)	97.6	96.6	96.8	97.9	97.1	96.8	97.4	97.5	97.2
Scat. Coefficient (cm^2/g)	587	552	535	607	575	538	566	544	524
R-48 fraction (%)	57.7	60.7	61.7	57.0	58.7	64.1	57.7	61.8	63.9
Fines (P-200) (%)	25.3	23.2	23.2	25.3	24.5	21.8	25.3	23.5	22.6
W. Weighted Average Fibre Length (mm)	2.36	2.40	2.45	2.57	2.53	2.82	2.25	2.49	2.55
L. Weighted Average Fibre Length (mm)	1.57	1.58	1.63	1.59	1.57	1.80	1.50	1.69	1.72
Arithmetic Average Fibre Length (mm)	0.58	0.58	0.60	0.49	0.51	0.56	0.58	0.61	0.62

Table II – 3 **PR930**

Sample	**72 Juvenile**			**72 Mature**			**72 Top**		
Unscreened Csf (mL)	64	109	140	66	110	151	72	123	154
Specific Energy (MJ/kg)	11.5	9.3	7.6	11.1	8.8	7.3	11.4	10.3	8.0
Screened Csf (mL)	63	108	138	64	105	141	70	108	150
Reject (% od pulp)	0.2	0.6	0.5	0.7	1.1	2.4	0.1	0.5	0.8
Apparent Density (kg/m^3) (1 Sheet)	400	352	334	372	340	319	393	373	361
Burst Index (kPa•m^2/g)	2.4	2.3	1.8	2.5	2.0	1.9	2.4	2.3	1.7
Tensile Index (N•m/g)	45.6	44.4	36.9	45.5	39.5	36.1	44.0	43.6	30.8
Stretch (%)	2.14	1.93	1.74	2.02	1.82	1.85	1.98	2.04	1.74
Tear Index (mN•m^2/g) (4 Ply)	6.1	6.6	7.6	7.7	7.9	7.9	6.2	6.7	7.0
Brightness (%)	54	53	53	53	53	52	51	51	50
Opacity (%)	98.5	98.1	97.9	98.5	97.7	96.9	97.3	96.8	97.6
Scat. Coefficient (cm^2/g)	675	594	602	656	607	547	535	526	502
R-48 fraction (%)	51.1	55.3	60.0	52.5	57.4	59.6	52.0	57.5	58.7
Fines (P-200) (%)	26.8	24.0	23.9	28.3	25.2	24.7	26.6	23.6	23.2
W. Weighted Average Fibre Length (mm)	2.04	2.10	2.33	2.53	2.54	2.66	2.02	2.14	2.30
L. Weighted Average Fibre Length (mm)	1.31	1.33	1.55	1.58	1.60	1.68	1.30	1.39	1.52
Arithmetic Average Fibre Length (mm)	0.51	0.52	0.59	0.50	0.52	0.53	0.52	0.55	0.56

Sample	**78 Juvenile**			**78 Mature**			**78 Top**		
Unscreened Csf (mL)	61	87	135	44	89	153	70	100	137
Specific Energy (MJ/kg)	11.3	10.1	8.3	11.6	9.4	7.8	10.5	9.7	8.1
Screened Csf (mL)	64	88	130	47	88	148	69	93	130
Reject (% od pulp)	0.5	0.9	1.5	0.2	0.3	1.1	0.2	0.5	0.7
Apparent Density (kg/m^3) (1 Sheet)	404	369	363	393	366	319	397	372	358
Burst Index (kPa•m^2/g)	2.7	2.6	2.2	3.0	2.3	2.0	2.6	2.6	2.3
Tensile Index (N•m/g)	50.3	47.9	42.4	54.0	47.3	38.7	49.7	47.8	44.1
Stretch (%)	2.03	2.19	2.00	2.16	2.06	1.82	2.08	2.12	1.93
Tear Index (mN•m^2/g) (4 Ply)	7.4	7.6	7.9	8.0	7.8	9.0	7.3	7.8	8.1
Brightness (%)	52	52	52	53	53	52	51	50	51
Opacity (%)	98.4	98.1	97.5	96.9	97.1	96.5	97.8	97.8	97.6
Scat. Coefficient (cm^2/g)	619	604	571	561	534	516	551	545	528
R-48 fraction (%)	55.3	59.7	61.3	55.7	59.0	65.4	55.8	60.8	61.6
Fines (P-200) (%)	28.1	25.0	24.3	29.7	24.0	21.5	26.5	25.3	24.1
W. Weighted Average Fibre Length (mm)	2.30	2.37	2.41	2.47	2.45	2.77	2.22	2.43	2.45
L. Weighted Average Fibre Length (mm)	1.55	1.63	1.66	1.60	1.56	1.86	1.49	1.67	1.71
Arithmetic Average Fibre Length (mm)	0.59	0.62	0.63	0.56	0.56	0.64	0.59	0.65	0.66

Table II – 4 **Old Growth**

Sample	**Western Hemlock**		
Unscreened Csf (mL)	77	102	137
Specific Energy (MJ/kg)	9.5	8.7	7.6
Screened Csf (mL)	80	100	139
Reject (% od pulp)	0.7	1.3	2.3
Apparent Density (kg/m^3) (1 Sheet)	317	298	286
Burst Index (kPa•m^2/g)	2.7	2.5	2.3
Tensile Index (N•m/g)	47.3	43.5	36.5
Stretch (%)	2.17	2.05	1.84
Tear Index (mN•m^2/g) (4 Ply)	9.5	10.0	9.4
Zero Span Breaking Length (km)	9.9	9.9	9.9
Sheffield Smoothness	205	244	253
Brightness (%)	50	50	50
Opacity (%)	98.9	98.2	97.4
Scat. Coefficient (cm^2/g)	671	586	547
R-48 fraction(%)	53.3	60.7	64.2
Fines (P-200) (%)	33.6	25.8	23.4
W. Weighted Average Fibre Length (mm)	2.63	2.73	2.80
L. Weighted Average Fibre Length (mm)	1.65	1.69	1.76
Arithmetic Average Fibre Length (mm)	0.49	0.49	0.51

SECTION 9

CONCLUSIONS

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SECTION

9

CONCLUSIONS

This study of second-growth western hemlock was undertaken with two objectives. First, to quantify for foresters the extent to which stand density management decisions affect end-product attributes; second, to provide manufacturers with a better understanding of the product potential of this future resource.

The results with respect to solid wood properties are unequivocal in their consistency. Lower stand density and higher site index at PH580 resulted in trees characterized by comparatively rapid early growth rate, lower average wood density and larger branch size. These characteristics in turn resulted in lower structural properties observed for lumber, veneer and small clear wood specimens.

Early rate-of-growth proved to be a more effective measure than stand density at 90 years for discriminating stands on the basis of wood attributes. Early growth rate at PH930 exceeded that at PR930, and was associated with significantly lower breast-height average wood density, and with significantly lower lumber strength and stiffness properties for the most prevalent lumber dimension (105x105 mm). Tests of small clear material provided results consistent with those obtained from full sized lumber tests, but differences between PH930 and PR930 were not significant. Previous studies of small clear western hemlock specimens found reduced strength and stiffness to be related to increased growth rate. The higher wood density and increased lumber strength and stiffness associated with moderate rate of growth to 30 years for the PR930 stand was consistent with previous observations about lodgepole pine.

Mean MOE values for Select Structural 105x105 mm lumber obtained from the two 930 sph stands of second-growth western hemlock equalled or exceeded existing design standards. Mean MOE values for the slow-grown PR930 stand also exceeded a previously published value for old-growth western hemlock. However, mean MOE for Select Structural squares from the relatively fast grown PH580 stand was lower than the current Select Structural design standard for Hem-Fir.

The 5th percentile MOR values for the two 930 sph stands equalled or exceeded the Hem-Fir design value. For the PH580 stand, 95 percent confidence intervals for the 5th percentile MOR values generally included the design value, but fell below it in the 50 and 60 cm tree d.b.h. classes.

Log grade rules which provide a first order estimate of value, resulted in relatively higher proportions of PH580 log volume being assigned to high value log grades primarily on the basis of larger log diameter. Lumber recovery was higher from larger diameter logs, but the proportion of premium NLGA and JAS grades obtained declined significantly as tree d.b.h. increased. Visually assigned lumber grades, a second order estimate of value, were more accurate in discerning differences in lumber structural properties between stands. However, significant differences in MOE and MOR in Select Structural lumber grades went undetected. Comparisons of end-product potential from stands and trees that go only as far as log grade estimates and visual lumber grade yields will not reveal significant differences in product value that may result from stand density management practices.

Definitions of juvenile wood as zones 15 and 30 annual rings from the pith provided poor predictions of the strength and stiffness of individual lumber pieces, but there were significant differences in mean MOE and MOR values between discrete 20 percent classes of juvenile wood proportions. Increased proportions of juvenile wood were associated with significant reductions in MOE and MOR.

Various measures of knot size (measured on the logs) provided relatively poor estimates of percentage yields of premium NLGA and JAS lumber grades. However, the relationships were stronger than those obtained for a similar study of Douglas-fir. Average knot size, which provided the best estimate of knot effects on lumber grade in studies of lodgepole pine and Douglas-fir, remained one of the best measures in this study, but easier to obtain knot indices proved to be equally effective. Predictions of mean MOE and MOR based on tree d.b.h. and breast-height wood density were improved only slightly by the inclusion of knot size.

Second-growth western hemlock in general was found to treat more readily than old-growth western hemlock. For manufacturers interested in the potential for sorting second-growth western hemlock to its best end use, the results of treatability tests show that wood from the more rapidly grown PH580 stand could find value in growing markets for treated wood products.

A very low level of variation was observed in the pulping and pulp properties of second-growth western hemlock. Second-growth western hemlock kraft pulp yields at kappa 30 were found to exceed published values by 1 to 2 percent which should significantly improve digester productivity. Pulp yield from top logs and juvenile wood was lower than that of mature wood by approximately 2 percent for a given kappa number. The largest tree from PH580 had a significantly lower pulp yield. In thermomechanical pulping, mature wood obtained from the PH580 stand exhibited poorer tensile strength compared to that from the other two stands. To take best advantage of differences in pulp properties, top logs and thinnings with high proportions of juvenile wood should be sorted out.

Logs from PH930 and PR930 produced high yields of structural veneer suitable for the manufacture of LVL. By virtue of their higher recovery, larger logs from the PH580 stand could be valuable in the production of appearance grade veneer.

Machining tests showed that second-growth western hemlock had machining properties similar to those of old growth.

Trends in early growth rate recorded here can be compared to those observed for western hemlock stands with known establishment history to provide inferences about the effects of stand density management on future wood product attributes.

Foresters responsible for stand density management can expect that second-growth western hemlock from stands similar to PH930 and PR930 will have structural properties that equal or exceed design standards for Hem-Fir. In determining initial spacing on very good sites, they should take into consideration the significantly lower structural properties of lumber obtained from the more rapidly grown trees from PH580. By careful attention to stand density management in relation to site, they can produce future forests with wood product attributes that are comparable to, or exceed, those of old-growth western hemlock.